

Functional aerobic capacity and body size

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SUMMARY An endurance treadmill exercise test protocol of two minute stages of increasing speed and gradient has been designed and evaluated for children under 10 years of age. There was a significant relation between test protocol time and oxygen uptake measured in ml/kg/min in tests performed on 20 subjects.

One hundred and sixty exercise tests performed in a semi longitudinal study of healthy primary schoolchildren were used to assess the relation of functional aerobic capacity with age and size. In boys functional aerobic capacity measured by predicting maximal oxygen uptake from endurance time in the treadmill test increased from 33.8 ml/kg/min at age 5 to 50.5 ml/kg/min at age 9.5 and was most closely related to age. The variables of size were not significant in predicting functional aerobic capacity for boys. In girls functional aerobic capacity increased from 34.9 to 43.5 ml/kg/min at the same ages and was related positively to lean body mass and age but negatively to weight. For girls lean body mass contributed 53.9% to the variance of functional aerobic capacity in stepwise multiple regression, weight 7.7%, and age 3.5%. A significant difference between the sexes was found.

Endurance treadmill exercise testing may be used to assess physical fitness, the endurance time in a standardised test protocol being proportional to maximal oxygen uptake or aerobic capacity. Standards are not readily available, however, for children in the United Kingdom.

The Bruce protocol test, in which the subject exercises to exhaustion on a treadmill through a fixed protocol of three minute stages of increasing speed and gradient, has been used in both adult and paediatric practice.^{1 2} Experience with this test in children under 10 years of age has, however, revealed practical difficulties. The work increments between successive stages are too great, resulting in endurance times that are biased towards the first half of the current stage. Children aged under 10 only rarely achieve the fifth stage of the Bruce protocol, confirming the observations of Cumming *et al*,² and never the sixth or seventh stages. Thus the time from the 12th to the 21st minute is effectively unused. The three minute stages are too long for young subjects, who become bored waiting for the next increment. Finally, the increments of work between stages, calculated from the treadmill speed and gradient, are unequal, leading to the need for several linear regression equations or a complex power equation to predict functional aerobic capacity.³

A similar type of test protocol, retaining the undoubted advantages of this form of treadmill test,² has therefore been designed with young children in mind. This paper describes the test, the relation between protocol time and oxygen uptake, and a semi longitudinal survey of British primary schoolchildren that provides a provisional range for physical fitness measured in terms of functional aerobic capacity, which is expressed as predicted maximal oxygen uptake in normal children aged between 5 and 9 and its relation with body size.

Subjects and methods

Normal children from three primary schools in Sheffield were invited to join the study. They were recruited at the age of 5, 6, or 7 years, and exercise tests were performed at six monthly intervals over a two year period.

At the first visit a full clinical history was taken and a clinical examination performed to exclude any child with chronic disease and to determine pubertal state. The child's usual daily pattern of activity was established, noting particularly any special physical activity not in the normal school timetable, whether the child was taking part in the normal school physical education lessons, and any time spent outside school hours in team sports or training

sessions. The extent of the parents' participation in sports and physical activity was also explored.

At subsequent visits enquiries were made into recent health and clinical examinations performed if indicated. Subjects who were unwell or who were recovering from minor acute illnesses had their tests postponed until they were fully recovered.

Anthropometry. Age was calculated in years and fractions expressed as decimals. In some analyses data were grouped into half year age bands; an age between 6.25 and 6.74 years would be in the 6.5 year band. When two tests were performed on the same subject while in the same age band the data from one only were included, the test being chosen randomly.

Height and sitting height were measured to the nearest completed millimetre. Subischial leg length was calculated. Standard deviation scores for height, sitting height, and leg length were calculated from nationally accepted data.⁴ Weight was measured to the nearest completed 50 g. Skinfold thickness was measured at four sites on the left side of the body. Mid-triceps, mid-biceps, subscapular, and suprailiac folds were measured to the nearest completed 10th of a millimetre. Body density, percentage fat, and hence lean body mass were calculated from weight and skinfold thickness measurements using formulas developed for children.⁵

Spirometry. Single expired breath spirometry was performed before and five minutes after the end of exercise. Peak expiratory flow rate was recorded as the best attempt of three after instruction using a Wright Peak Flow Meter.

Exercise testing. Table 1 describes the endurance exercise test protocol of two minute stages of increasing speed and gradient. The electrocardiogram was monitored throughout the exercise test, and 10 second permanent records were made at the end of each minute of the test and at the child's

point of exhaustion, from which the heart rates were later calculated.

The test was supervised at all times by two persons, the author and one of two assistants, both experienced paediatric nurses and trained in techniques of exercise testing and resuscitation.

As the speed and gradient increased the child was encouraged to walk and then jog or run until exhausted. The end point for exhaustion, or endurance time, was largely determined by the child's subjective experience, but certain objective criteria were also used whenever possible. A heart rate of at least 195 beats/min was aimed for.⁶ Cold sweating, facial pallor, particularly circumoral pallor, unsteadiness of gait, or incoordination and faintness were used as signs of impending central cardiovascular exhaustion,⁷ as opposed to peripheral limitation, which presents with fatigue, pain, and muscle weakness. It is emphasised, however, that despite non-achievement of these objective criteria a child's unwillingness to proceed further, hanging onto the hand rail, or becoming distressed was interpreted as an indication of having reached functional exhaustion, the psychological component of physical fitness being considered important. The predicted oxygen uptake at this point was termed the functional aerobic capacity.

Oxygen uptake. Oxygen uptake was measured in a subgroup drawn from the study population. A commercially available system (Oxycon 4, Gebr Mijnhardt BV, Odjic, Netherlands) was used. Oxygen uptake expressed as ml/kg/min was measured continuously and averaged over 30 second periods throughout the tests.

Statistical methods. Data were analysed by Student's *t* test and conventional multiple regression techniques, implemented by the statistical package Minitab (Copyright, Pennsylvania State University, 1982).

Results

Oxygen uptake. Twenty tests on 11 boys and nine girls aged between 6.2 and 9.9 years were performed. In both sexes there was a highly significant relation between protocol time and measured oxygen uptake ($r=0.95$ for boys and 0.92 for girls). As there was no significant difference between the values for either sex (*t* test, $p>0.1$) the data were pooled and the following regression equation obtained:

oxygen uptake (ml/kg/min) = $14.79 + 2.50 \times$ endurance time (min).

Table 1 *The endurance exercise test protocol*

Two minute stage	Speed (km/h)	Gradient (%)	Theoretical workload (kpond m/min)
1	3.0	10	5.0
2	3.8	12	7.5
3	4.3	14	10.0
4	4.7	16	12.5
5	5.0	18	15.0
6	5.5	19	17.5
7	6.0	20	20.0
8	6.4	21	22.5
9	6.8	22	25.0

This was a highly significant linear relation ($r=0.93$, residual $SD=2.44$, $p<0.001$); therefore, functional aerobic capacity could be predicted directly from endurance time in the test.

There were no significant differences between the measured oxygen uptakes found in this study and the theoretical values predicted by the equation given by the International Committee for the Standardisation of Physical Fitness Tests.⁸

Functional aerobic capacity. Altogether 160 tests were performed on 57 children (27 boys and 30 girls). Seventy four tests were carried out on boys and 86 on girls. The age range of the subjects was 4.9–9.9 years. No child had an unusual exercise pattern, and none was excused school games or physical education. No parent did other than occasional recreational exercise.

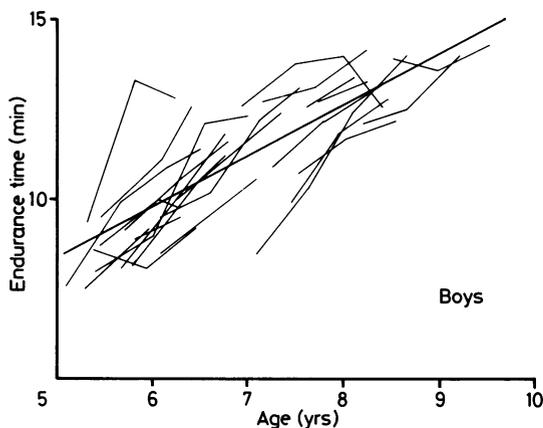


Fig. 1 Endurance time and age for boys.

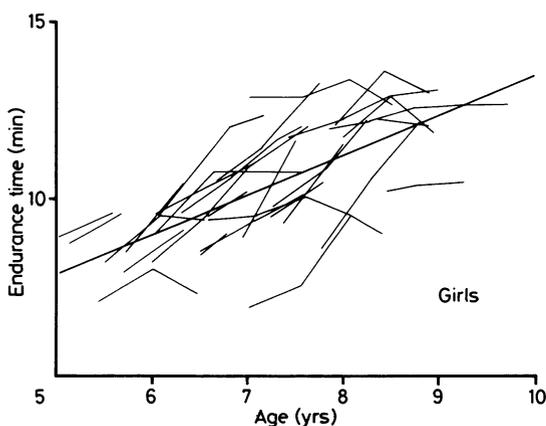


Fig. 2 Endurance time and age for girls.

All the subjects were normally grown, and none was disproportionate. All were prepubertal throughout the study and of European ethnic origin.

The maximum (SD) heart rate achieved at the end of maximal exercise was 201.1 (8.9) beats/min for boys and 202.2 (10.1) beats/min for girls. The relation between maximum heart rate and age was not significant. Similarly, there was no correlation between maximum heart rate and endurance time.

Figures 1 and 2 show individual endurance times with the regression line for endurance time against age for boys and girls. Figure 3 shows the means and standard deviations for endurance time and hence predicted maximal oxygen uptake in each half year age band for boys and girls separately.

For boys the regression equation was:

$$\text{endurance time (min)} = 1.24 + 1.42 \times \text{age (yrs)}$$

This correlation was significant ($r=0.816$, residual $SD=1.12$, $p<0.01$). For girls the regression equation was:

$$\text{endurance time (min)} = 2.55 + 1.08 \times \text{age (yrs)}$$

This relation was also significant ($r=0.683$, residual $SD=1.57$, $p<0.01$).

At age 5.0 years the mean endurance time for boys was 7.6 minutes, corresponding to a maximal oxygen uptake of 33.8 ml/kg/min. For girls the mean endurance time was 8.0 minutes, corresponding to a

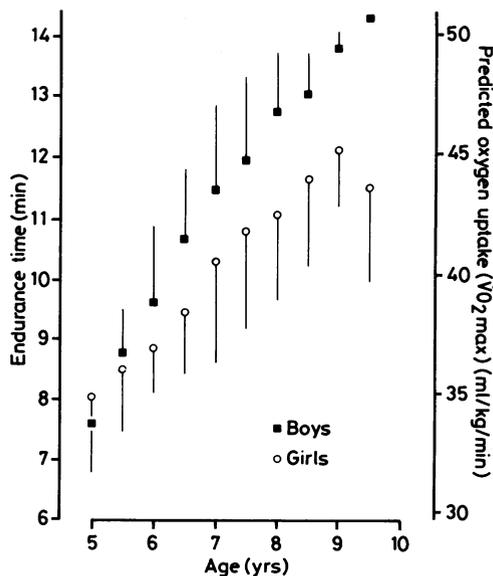


Fig. 3 Mean and standard deviation for endurance time and predicted functional aerobic capacity for boys and girls in half year age bands.

maximal oxygen uptake of 34.9 ml/kg/min. At age 9.5 years the mean endurance time for boys was 14.3 minutes and for girls was 11.5 minutes, corresponding to maximal oxygen uptakes of 50.5 and 43.5 ml/kg/min, respectively.

In age bands 6.5, 8.0, 8.5, and 9.0 years the difference between endurance times for boys and girls was significant (*t* test, $p < 0.05$). At the other ages the difference between the sexes was not significant at the 5% level.

Using multiple regression for boys age was the only significant predictor of endurance time (Table 2). Altogether, 69.5% of the variance of endurance time was predicted by the regression, and of this

Table 2 Multiple regression analysis of relation between endurance time and age and anthropometric measurements for boys, girls, and both sexes

	Regression coefficient	Sum of squares explained by variable	p Value
Boys:			
Constant	-2.56		
Age (yrs)	1.29	179.17	<0.01
Height (cm)	0.05	2.15	NS
Leg length (cm)	0.08	0.97	NS
Weight (kg)	-0.23	2.91	NS
Lean body mass (kg)	0.26	1.92	NS
Residual SD	1.10	82.08	
Girls:			
Constant	3.24		
Age (yrs)	0.45	8.74	<0.05
Height (cm)	-0.06	0.16	NS
Leg length (cm)	0.07	0.51	NS
Weight (kg)	-0.34	19.14	<0.01
Lean body mass (kg)	0.77	113.43	<0.01
Residual SD	1.04	85.70	
Both sexes:			
Constant	0.23		
Age (yrs)	0.90	289.39	<0.01
Sex*	1.17	14.74	<0.01
Height (cm)	-0.01	11.51	NS
Leg length (cm)	0.01	0.82	NS
Weight (kg)	-0.30	1.89	<0.01
Lean body mass (kg)	0.55	26.24	<0.01
Residual SD	1.11	186.91	

*Boy=1, girl=0.

Table 3 Stepwise regression of girls' endurance times against age and anthropometric variables (three steps only were necessary, the remaining variables not contributing significantly)

Step	Regression coefficients					r Value
	Constant	Lean body mass (kg)	Weight (kg)	Age (yrs)	Residual SD	
1	1.92	0.43			1.17	0.734
2	1.70	0.85	-0.33		1.07	0.785
3	0.91	0.71	-0.33	0.46	1.03	0.807

Table 4 Stepwise regression of endurance times for boys and girls against age, sex, and anthropometric variables (four steps only were necessary, the remaining variables not contributing significantly)

Step	Regression coefficients						r Value
	Constant	Age (yrs)	Sex*	Lean body mass (kg)	Weight (kg)	Residual SD	
1	2.56	1.15				1.32	0.693
2	1.35	1.24	1.13			1.20	0.756
3	0.64	0.91	1.08	0.16		1.16	0.776
4	0.09	0.90	1.17	0.56	-0.30	1.10	0.805

*Boy=1, girl=0.

fraction 95.8% was attributable to age. Thus age contributed 66.6% to the total variance of functional aerobic capacity, and the other variables only contributed a further 2.9%.

In girls the analysis showed a different pattern of relation (Table 2). Stepwise regression showed that lean body mass, age, and weight were significant predictors of endurance time (Table 3). Thus, of the 65.4% of the variance of endurance time explained by the regression equation (almost the same proportion as for boys), 82.1% was contributed by lean body mass, 11.7% by weight, and 5.3% by age. Hence lean body mass contributed to 53.9% of the total variance of functional aerobic capacity, weight 7.7%, and age 3.5%.

When sex was taken into account alongside age and the anthropometric variables as a factor predicting endurance time it was also found to be significant (Table 2), confirming the differences in functional aerobic capacity between the sexes shown when the data were analysed in age bands (Fig. 3). Stepwise regression (Table 4) showed that of the 64.9% of the total variance of endurance time that was explained by the regression equation, 74.1% was due to age and a further 14.1% was due to sex. Hence 9.1% of the total variance of functional aerobic capacity was attributable to sex.

Discussion

Work physiologists generally agree that measurement of maximal oxygen uptake is the standard for assessment of physical fitness,⁹ but they do not agree about the criteria for having attained this. Astrand, and others since, have required their subjects to have accumulated a substantial oxygen debt measured in terms of blood lactate concentration.¹⁰ Blood sampling, even taking a capillary sample, from the normal children in this study for non-therapeutic purposes could not be

justified ethically. In addition, a traumatic experience might have diminished cooperation. Other workers have required a plateau of oxygen uptake despite increasing workloads,¹¹ and yet others recognise that the plateau is difficult if not impossible to achieve in children and allow the subject to decide his own functional end point.^{2 12} This is the present author's choice of end point and is the reason for the term 'functional aerobic capacity' being used.

The design of the test protocol was evaluated by measuring oxygen uptake directly during tests to predict maximal oxygen uptake from endurance time. A linear relation of oxygen uptake with test protocol time has been found; functional aerobic capacity was, therefore, predicted directly from endurance time.

In terms of their physiological responses the children studied seemed to be normal and healthy. Their spirometric measurements at rest were normal, and the response to exercise was within normal limits apart from in seven out of the total of 180 tests when mild exercise induced bronchospasm was detected. In only two cases was this symptomatic, and the onset of symptoms was after the end of the exercise test. The maximum heart rate achieved at the end of maximal exercise in the group as a whole was within the accepted range of normal.⁹ In no case was heart rate alone used as a criterion of maximal effort. A child showing other subjective or objective signs of impending exhaustion was considered to have performed to his or her limit even in the absence of achieving the heart rate of 195 beats/min that has been regarded as a minimum target.⁶ Similarly, a child achieving a heart rate of 210 beats/min, or in one case over 220 beats/min, without showing signs of central exhaustion was encouraged to continue until showing these signs.

The pattern of development seen was of an increase in functional aerobic capacity with increasing age and size. It was related most strongly to age in boys and to lean body mass in girls. At the younger ages there was little difference between the values for both sexes, but as age increased the differences became significant. When analysed in half year age bands the values at ages 6.5, 8.0, 8.5, and 9.0 were significantly different.

Analysis of the variance of endurance time by multiple stepwise regression showed that for boys endurance time, and thus functional aerobic capacity, was predicted significantly by age alone. For girls, however, lean body mass, weight, and age were all significant variables, endurance time being influenced positively by lean body mass and age but negatively by weight. This does not confirm the suggestion that analysis by multiple regression has

no advantage to offer over the more straightforward method of linear regression in predicting functional aerobic capacity.¹³ It does, nevertheless, fit in with the clinical impression that, although the older boys tended to have longer endurance times whatever their size or shape, it was the less 'podgy' girls who had greater functional aerobic capacities.

These data are compatible with the findings of previous studies, largely of North American and Scandinavian origin, in which an increase in aerobic capacity with age was noted.^{2 14-17} They do not concur with others who have found no difference in maximal oxygen uptake with age in prepubertal children.^{10 13} The significant differences found between the sexes, boys having significantly greater endurance times than girls when all other variables were taken into account, concurs with the findings of previous work in which greater working capacities were noted in boys than in girls of the same size.^{15 16 18}

There are obvious differences in the physiological responses of boys and girls. In all studies, including this one, girls have tended to achieve higher maximum heart rates. There is also evidence that in girls, particularly as they become heavier and older, there is greater participation of energy production from anaerobic metabolism than in boys.¹⁹ This may make girls less tolerant of acute exercise. It has been shown that at a given oxygen uptake girls have a higher heart rate, higher cardiac output, and lower arteriovenous oxygen difference than boys, but the differences could not be explained.²⁰

Cultural differences between the sexes in childhood are easy to identify but hard to quantify; many girls are encouraged into more sedate pastimes. As all but the most intensive training regimens have, however, been shown to have little influence on aerobic capacity in either sex before puberty,^{21 22} young girls, like young boys, probably maintain a level of spontaneous activity that leads to a fairly high degree of fitness.

It is not possible to explain fully the differences seen between boys and girls in the pattern of relations of functional aerobic capacity with age and anthropometric factors on the basis of the data collected. It is of great importance, however, to note that in both sexes there was an increase in functional aerobic capacity measured in terms of oxygen uptake per unit mass with increasing age and size, implying that there is a process of maturation of physical abilities taking place, and that functional aerobic capacity was predicted best in boys by age and in girls by lean body mass.

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