Cardiopulmonary response to exercise of 8- and 13-year-old Chinese children in Hong Kong: results of a pilot study

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Objectives. To assess the cardiopulmonary response of healthy Hong Kong Chinese children to the treadmill test, and to identify anthropometric factors that may be related to fitness.
Design. Cross-sectional study.
Setting. University teaching hospital, Hong Kong.
Participants. Forty-three 8-year-old and fifty-seven 13-year-old healthy Chinese children from middle– or lower–socio-economic class families in Shatin and nearby areas.
Main outcome measures. The forced vital capacity, 1-second forced expiratory volume, pulse rate, and blood pressure were measured before and after undertaking the treadmill test (Bruce protocol). The endurance time until volitional exhaustion, the number of metabolic equivalents of energy used, and the sum of the skinfold thicknesses were also obtained.
Results. Multiple regression analysis showed that the sum of the skinfold thicknesses was positively associated with pulse rate and diastolic blood pressure at all stages of exercise, and was negatively associated with the endurance time and the number of metabolic equivalents of energy used by the 8-year-old children. The 13-year-old children had a longer cardiopulmonary endurance than the 8-year-old children. In both age-groups, pulmonary function was positively associated with height and weight.
Conclusion. The study provides useful reference data for Hong Kong Chinese 8- and 13-year-old children when subjected to the treadmill test. A larger study is needed to establish the normal standards for children of all different ages.

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Key words: Adolescent; Blood pressure; Body mass index; Child; Exercise test/standards; Heart rate; Respiration; Skinfold thickness

Introduction

In the early 1960s, Field and Baber[1] reported that children in Hong Kong had a suboptimal nutritional status and poor patterns of growth. In contrast, recent evidence has shown that obesity is becoming an increasing problem among Hong Kong children.[2] Because of the association between obesity and cardiovascular morbidity and mortality, the assessment of fitness and fatness have become important to identify at-risk individuals. However, a consensus has not been reached as to which fitness tests are most practical and appropriate for clinical use. Hospital-based practitioners usually choose to use the treadmill test because it is a well standardised method that evaluates cardiac arrhythmia, chest pain, and cardiopulmonary response in adults. The treadmill test does not require prior experience or practice and is thus suitable for children; unlike the ergometer, the equipment does not require calibration.

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An increasing number of tests have been designed for children in the past 20 years, mainly to evaluate cardiopulmonary fitness or arrhythmia, and also to assess exercise-induced changes in airway resistance. The interpretation of test results has however been problematic, because very little data regarding the reference standards for children are available in the literature.[3-9] Apart from two studies from Beijing,[8,9] all other investigations have been conducted in non-Chinese children, whose anthropometric parameters, nutritional status, and physical activity may be quite different from their Chinese counterparts. It is therefore necessary to determine reference standards for Chinese children, so that their performance of the treadmill test, for example, can be better evaluated. In this pilot study, the treadmill test and simple pulmonary function test were performed in two age-groups of Chinese children and an attempt was made to identify the anthropometric factors that may be related to the cardiopulmonary fitness.

Methods

Participants

A group of 43 healthy Hong Kong Chinese children (25 boys and 18 girls) aged from >8 to <9 years, and a group of 57 healthy Chinese teenagers (31 boys and 26 girls) aged from >13 to <14 years took part in the study at the Prince of Wales Hospital. The study was approved by the Ethics Committee of the Faculty of Medicine, The Chinese University of Hong Kong. Informed consent was obtained from the parents. The children in the younger age-group were part of a cohort of an ongoing longitudinal growth study in Hong Kong.[10] Children in this cohort are from middle– or lower–socio-economic class families in Shatin and nearby areas, and all have been growing normally since their random recruitment at birth in 1984. The teenagers belonged to a cohort from a study of the effects of diet and physical activity on physical fitness and bone mass among secondary level schoolchildren in Shatin.

Prior to entering the study, a questionnaire was completed by the teenagers and parents of the 8-year-old children regarding their physical fitness and past medical history. Children who had a history of asthma or other medical conditions that may have affected the cardiopulmonary response to exercise were excluded from the study. All participants were screened by a pediatrician to confirm that there were no pre-existing medical conditions that might have affected their exercise performance. The physical examination included an evaluation of the stage of puberty reached using the Tanner criteria. For the boys, the developmental stage of the genitalia, presence of pubic hair, and testicular size were recorded; for the girls, the developmental stage of the breasts, presence of pubic hair, and menarche were recorded.

Anthropometric methods

The weight of each participant, while wearing a short-sleeved cotton T-shirt and shorts, was measured using electronic scales (Seca, Vogel & Halke GmbH & Co., Hamburg, Germany) to the nearest 0.1 kg. The standing height was measured using a wall-mounted stadiometer (prepared by the Technical Services Unit of The Chinese University of Hong Kong) to the nearest 0.1 cm, while the participants' occiput, back, and bare heel were touching the stadiometer. The body mass index (BMI) was calculated by dividing the weight in kilogrammes by the square of the height in metres. The subcutaneous skinfold thickness at four sites—namely, the biceps, triceps, subscapular area, and suprailiac area on the left side of the body—was measured using Holtain calipers (Crosswell, Pembrokeshire, United Kingdom). Two measurements were taken at each site and the mean of the two values was determined.

Treadmill test

Aerobic fitness was assessed by using a Quinton 2000 Treadmill (Quinton Instruments, Seattle, United States). The treadmill was programmed to increase in gradient and speed every 3 minutes, in seven stages, according to the Bruce protocol.[11] The test room was air-conditioned and had a constant temperature of 23°C and relative humidity of 60%. The children were asked to wear a light T-shirt and shorts, and to restrict their food intake for a least 1.5 hours before the test. The procedure was conducted either in the morning or mid-afternoon and no children had prior experience of using the treadmill. The test procedure was explained by a nurse and the next participant was encouraged to watch the running of the test in the test room. The children were instructed to hold onto the handrails lightly to ensure safety. The pulse rate and electrocardiogram (ECG) were monitored continuously during and until 5 minutes after the test. The blood pressure was measured before exercise and at each stage of the treadmill test using an electric manometer that was connected to a programmable air-compression cuff system (Colin stress-test blood pressure monitor, Model STBP-780; Colin Co., Komaki City, Japan). One of two different cuffs of sizes (8 x 18 cm or 12 x 24 cm) were used, depending on which was wide enough to cover at least two thirds of the length of the upper arm and long enough to encircle the arm. Each child was encouraged verbally and urged to continue running to the point of exhaustion.

Pulmonary function test

A Vitalograph spirometer (Vitalograph Ltd., Buckingham, United Kingdom) was used to determine the forced vital capacity (FVC) and 1-second forced expiratory volume (FEV_1) of each participant before and after undertaking the treadmill test. The peak expiratory flow rate (PEFR) before the test was measured using a Wright Peak flow meter (Clement Clarke International Ltd., London, United Kingdom); the PEFR was also measured immediately after the test and every 5 minutes for a further 20 minutes.

Statistical analysis

Data were analysed separately for the two age-groups of children. Descriptive statistics (means and standard deviations) were determined for all the variables. Gender differences in anthropometric measurements and aerobic fitness were compared by using a two-tailed Student's *t* test. Multivariate regression analysis was used to analyse the relation between anthropometric measurements, pulse rate, and blood pressure at different stages of exercise. Stepwise regression analysis was used to determine the relation between anthropometric measurement, exercise endurance time, metabolic equivalents (METs) used, FVC, and PEFR. Each analysis was performed for the whole group of 8-year-old children using height, weight, and sum of the values for skinfold thickness as independent variables; the pulse rate, blood pressure, exercise time, METs used, FVC, and PEFR were used as dependent variables. The same analyses were repeated for the 13-year-old children, with sex and pubertal staging as additional independent variables. All statistical analyses were performed by using the Statistical Package for Social Science (Windows version 6.0; SPSS Inc., Chicago, United States).

Results

All children who participated in this study were in good health. The questionnaires showed that the average length of exercise for the 8-year-old children was 2.8 (standard deviation, 0.9) hours per week. There was no difference in the activity level between boys and girls, although 13-year-old boys participated more in physical activities than girls of the same age-group. The average time of exercise was 7.7 (4.3) hours per week for boys and 5.9 (3.6) hours per week for girls. All participants were highly motivated about the test. The 13-year-old children were particularly enthusiastic because of peer influence. Fear of injury or performing on the treadmill were not problems.

Occasional ventricular beats were observed in one adolescent girl at rest, but they disappeared after exercise had reached stage 2 of the treadmill test. No other participant's ECG showed arrhythmia or ischaemic changes. At high pulse rates (>150 beats per minute), J-depression was common but the ST segment was always upward. No child had a downward or horizontal ST segment at 0.08 seconds after the QRS complex.

The anthropometric measurements, exercise endurance time, METs achieved, and pulmonary function test results are shown in Table 1. There were no significant differences in most variables between the two sexes, but the BMI, FVC, and PEFR were higher for the boys. There were significant differences in the height and weight between boys and girls in the adolescent group and the BMI and skinfold thickness were higher in girls. The adolescent boys achieved higher METs and longer exercise endurance time than did the adolescent girls. The pulse rate and blood pressure at each stage of the treadmill test and at recovery are shown in Tables 2 and 3. Serial changes in the PEFR after the treadmill

Table 1. Anthropometric measurements, exercise endurance time, metabolic equivalents, and respiration measurements of Hong Kong Chinese children and adolescents

	Children			Adolescents		
	Boys (n=25) Mean (SD)	Girls (n=18) Mean (SD)	P value	Boys (n=31) Mean (SD)	Girls (n=26) Mean (SD)	P value
Weight (kg)	22.50 (3.90)	20.20 (4.10)	ns	44.60 (8.10)	46.40 (7.00)	ns
Height (cm)	120.10 (4.60)	118.10 (5.60)	ns	158.70 (8.10)	155.50 (6.10)	ns
BMI* (kg/m^2)	15.50 (1.86)	14.30 (1.67)	0.04	17.58 (2.27)	19.15 (2.45)	0.02
SSF† (mm)	29.49 (14.71)	27.75 (17.11)	ns	23.72 (10.83)	37.60 (14.16)	<0.001
Endurance time (min)	11.70 (1.70)	11.60 (1.90)	ns	15.70 (2.20)	13.30 (2.10)	<0.001
METs‡	13.30 (1.60)	12.90 (1.60)	ns	15.80 (1.70)	14.40 (1.60)	0.002
FVC§ (L)	1.51 (0.36)	1.26 (0.44)	0.001	3.55 (0.68)	3.04 (0.58)	<0.001
FEV_1xx (L)	1.30 (0.35)	1.14 (0.42)	0.05	3.16 (0.63)	2.73 (0.43)	0.02
PEFR¶ (L/min)	252.00 (37.50)	250.00 (35.50)	ns	438.40 (57.80)	407.30 (46.40)	0.01

* BMI body mass index
† SSF sum of skinfold thicknesses
‡ METs metabolic equivalents (1 MET = 3.5 mL oxygen per kg body weight per minute)
§ FVC forced vital capacity
xx FEV_1 1-second forced expiratory volume
¶ PEFR peak expiratory flow rate
ns not significant

Table 2. Mean pulse rates* of Hong Kong Chinese children and adolescents at different stages of the treadmill test

Test stage	Children				Adolescents			
	Boys (n=25)		Girls (n=18)		Boys (n=31)		Girls (n=26)	
	Mean pluse rate (SD)	n	Mean pluse rate (SD)	n	Mean pluse rate (SD)	n	Mean pluse rate (SD)	n
Pre-exercise	99 (12)	25	96 (10)	18	94 (14)	31	97 (14)	26
Exercise stage 1	132 (18)	25	136 (16)	18	124 (12)	31	135 (16)	26
2	146 (16)	25	153 (17)	18	138 (12)	31	151 (15)	26
3	165 (16)	24	171 (18)	18	154 (15)	31	169 (14)	26
4	190 (12)	14	182 (12)	9	177 (16)	29	189 (9)	20
5	181	1	204	1	200 (10)	18	205 (4)	7
6	-	-	-	-	200 (12)	3	205	1
Maximum rate	192 (14)	25	193 (12)	18	201 (12)	31	199 (10)	26
Recovery: 1 min	-	-	-	-	-	-	-	-
2 min	128 (22)	25	135 (15)	18	149 (15)	31	153 (14)	26
5 min	117 (14)	25	121 (13)	18	127 (13)	31	127 (14)	26

* beats per minute

test are shown in the Figure. The maximum reduction in the PEFR after exercise was 4.0% and 5.6% in the 8-year-old boys and girls, respectively; the corresponding figures for the 13-year-old boys and girls were 5.5% and 0.2%, respectively.

Statistical analysis of the data showed that there was a significant negative correlation between the pulse rate at stage 3 of the treadmill test (ie submaximal exercise) and endurance time among the children (Pearson's product moment correlation coeficient [r]=-0.43; P<0.05), adolescent boys (r=-0.51; P<0.01), and adolescent girls (r=-0.39; P<0.05) [Table 4]. Height, weight, and skinfold thickness were highly correlated (r>0.50); consequently, when one of the three variables was entered into the regression model, the other two were less likely to be significant. Hence, each variable was analysed separately. The taller and heavier adolescent boys had higher blood pressure and better lung function. There were no associations between the METs achieved or exercise duration and the anthropometric data. The stage of breast development and height of the adolescent girls were associated with the METs achieved, while the body weight was associated with the FEV_1.

The sum of the skinfold thicknesses was the best reciprocal determinant of treadmill performance in 8-year-old children (Table 4c). Eight-year-old children who had a greater skinfold thickness also had a higher pulse rate and diastolic blood pressure, and performed less well in the treadmill test.

Discussion

The treadmill test was well accepted by all participants, especially the adolescent children, who were very

Table 3. Systolic and diastolic blood pressures of Hong Kong Chinese children and adolescents at different stages of

Test stage	Children					
	Boys (n=25)			Girls (n=18)		
	SBP* (SD)	DBP† (SD)	n	SBP* (SD)	DBP† (SD)	n
Pre-exercise	114 (14)	57 (14)	25	110 (14)	58 (12)	18
Stage 1	119 (16)	57 (14)	25	115 (14)	58 (13)	18
2	125 (19)	57 (13)	25	126 (20)	54 (17)	18
3	123 (23)	62 (15)	24	136 (32)	62 (14)	18
4	125 (19)	56 (21)	14	143 (28)	61 (9)	9
5	150	64	1	138	48	1
6	-	-	-	-	-	-
Maximum value	147 (18)	65 (17)	25	153 (27)	64 (15)	18
Recovery:						
1 min	121 (27)	53 (20)	25	127 (25)	48 (12)	18
2 min	131 (21)	56 (19)	25	131 (24)	59 (15)	18
5 min	131 (22)	67 (12)	25	124 (14)	55 (12)‡	18

* SBP systolic blood pressure
† DBP diastolic blood pressure
‡ P<0.01
§ P<0.05

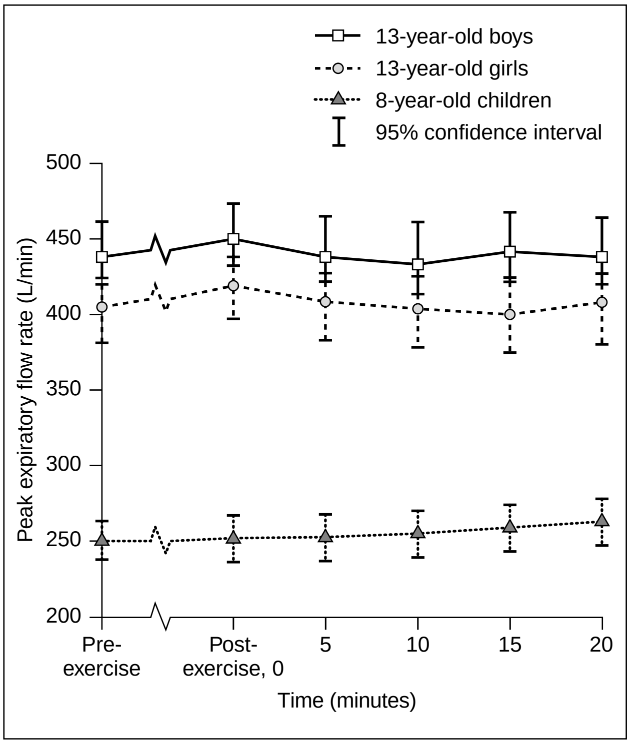

Fig. Peak expiratory flow rate of children and adolescents before and after undertaking the treadmill test

excited while waiting to perform the test. This observation explains why the resting pulse rate immediately before the treadmill test among the adolescent group was relatively high. Studies have shown that cardiopulmonary endurance increases with age in children and adolescents[3,5,12] and that children with less body fat are fitter.[6,7] This study also showed that adolescents perform better than 8-year-old children and that, in the 8-year-old age-group, the MET and exercise endurance time have a negative correlation with the sum of the skinfold thicknesses.

Contrary to previous reports that girls have a higher BMI and are less fit than boys,[7,13] this study found no difference between the fitness levels of 8-year-old boys and girls; in addition, the BMI was higher for the 8-year-old boys. Gilliam et al[13] have shown that boys aged 6 or 7 years in Michigan, United States are thinner and fitter than girls of the same age. Gutin et al[7] have shown that boys aged 5 or 6 years from inner-city New York are more aerobically fit than their female counterparts, although there was no significant difference in the skinfold thickness. The authors suggested the reason to be that the boys' parents believe that physical activity is more appropriate for boys than girls. In this study, however, parents reported low levels of physical activity for both 8-year-old boys and girls, an observation which explains the similarity in fitness level of boys and girls. Primary level school classes in Hong Kong usually last half a day, and most schools have 1.5 hours at most of physical education lessons each week. Children spend an average of 3 hours after school to do homework and consequently have very little time left for play outdoors. In spite of both sexes having low activity levels, boys have been reported to eat more food than girls[14] and this factor may contribute to the higher BMI among the boys in this study. In contrast to the primary level schoolchildren, 13-year-old girls in this study had lower levels of physical activity than the boys in this age-group. This result, and the fact that adipose tissue accumulates in girls at puberty,[15] explains the significantly higher BMI among these girls.

Blood pressure has a positive correlation with weight and height in children and adolescents.[16] This study also showed that the systolic blood pressure of

the treadmill test

Adolescents					
Boys (n=31)			Girls (n=26)		
SBP* (SD)	DBP† (SD)	n	SBP* (SD)	DBP† (SD)	n
126 (12)	70 (12)	31	113 (13)‡	62 (9)‡	26
133 (16)	65 (11)	31	128 (12)	61 (10)	26
139 (20)	65 (10)	31	132 (17)	60 (12)	26
143 (20)	63 (10)	31	137 (16)	64 (14)	26
149 (19)	62 (11)	29	141 (12)	64 (10)	20
142 (16)	63 (14)	18	142 (15)	66 (4)	7
139 (20)	62 (4)	3	133	71	1
163 (19)	62 (12)	31	153 (17)§	67 (13)	26
141 (23)	59 (11)	31	130 (17)	62 (10)	26
141 (15)	58 (14)	31	133 (14)	63 (14)	26
128 (15)	63 (12)	31	123 (10)	61 (11)	26

Table 4. Regression analysis of anthropometric factors associated with cardiopulmonary response in adolescents and 8-year-old children*

Significant factors	Regression coefficient	Goodness of fit	P value
(4a) Adolescent boys			
Significant factors	Regression coefficient	Goodness of fit	P value
SBP†; weight	0.83	Multiple correlation = 0.58	0.009
DBP‡; height	0.38	Multiple correlation = 0.59	0.016
FEV_1§; height	0.04	R^2=0.22	0.008
FVCxx; weight	0.03	R^2=0.13	0.043
(4b) Adolescent girls			
Significant factors	Regression coefficient	Goodness of fit	P value
SBP; breast development (B stage)	16.42	Multiple correlation = 0.58	0.031
METS¶; height	-0.15	R^2=0.30	0.007
METS; breast development	1.30	R^2=0.30	0.032
FEV_1; weight	0.04	R^2=0.31	0.002
FVC; weight	0.05	R^2=0.30	0.003
(4c) 8-year-old children			
Significant factors	Regression coefficient	Goodness of fit	P value
Pulse rate; sum of skinfolds	0.44	Multiple correlation = 0.67	0.001
DBP; sum of skinfolds	0.30	Multiple correlation = 0.54	0.002
METS; sum of skinfolds	-0.07	R^2=0.46	<0.001
Exercise time; sum of skinfolds	-0.05	R^2=0.23	0.004

* Only factors that showed a significant correlation with performance on the treadmill or with pulmonary function are shown

† SBP systolic blood pressure

‡ DBP diastolic blood pressure

§ FEV_1 1-second forced expiratory volume

xx FVC forced vital capacity

¶ METS metabolic equivalents

13-year-old girls positively correlated with their breast development. The relation between puberty and blood pressure of adolescents in the same age-group has not been previously reported, and a large-scale study is certainly worth pursuing. The FVC and FEV_1 of the 8- and 13-year-old children are comparable to those reported recently in Singapore.[17] Because bronchial asthma is very common in Hong Kong and exercise-induced wheeze is a frequently encountered symptom in asthmatic children, we measured the PEFR before and after the (non-asthmatic) children performed the treadmill test so as to provide reference values for further clinical investigation of exercise-induced asthma. The maximum reduction in the PEFR after exercise in both age-groups was not more than 6%, which is well below the accepted value for maximum reduction in PEFR after exercise in normal children (12.5%).[18] Although the treadmill test is widely used in the clinical setting, comparing the results from this study with others is difficult, because differing protocols have been used and only a few studies have used the Bruce protocol to study normal children.[3,5,19] The mean exercise endurance times in this study were 11.7 and 11.6 minutes for 8-year-old boys and girls, respectively, compared with the corresponding figures of 12.6 and 11.8 minutes from a Canadian study performed in 1978.[3] The mean exercise endurance times for the adolescent boys and girls were 15.7 and 13.3 minutes, respectively; these figures are greater than the values obtained in the Canadian study (14.1 and 11.1 minutes, respectively).[3]

The adolescent girls in this study also seem to have performed much better than American adolescent white and black girls (mean age, 13.5 [standard deviation, 1.6] years), whose endurance times were 9.4 and 8.5 minutes, respectively.[19] The average BMIs of the white and black girls in the American study, however, were higher (20.2 and 22.6 kg/m^2, respectively) compared with the BMI of Hong Kong girls (19.2 kg/m^2). Other factors that may have contributed to the difference in the exercise endurance time, include differences in the time period of data collection and the girls' technique of performing the treadmill test. In the American and Canadian studies mentioned, the children were not allowed to hold onto the handrails during the exercise, whereas in this study, we instructed all participants to hold onto the handrails lightly. Holding onto the rails might have reduced the metabolic cost of the work and increased the sense of safety; these factors may explain why the exercise endurance time was con-siderably lengthened.[20]

While Ding et al[8] reported in early 1980s on a much longer exercise endurance time for healthy Beijing children than was found in this study, Lin et al[9] showed the opposite trend in a study from 1989 to 1992 (Table 5). The anthropometric data reported by Lin et al were very similar to those in this study and there were no apparent methodological differences among the three studies. It would nevertheless be reckless to conclude that Beijing children have become less fit in the 1990s compared to those in the 1980s

Table 5. A comparison of body height, weight, and exercise endurance time between Beijing and Hong Kong 13-year-old children

Study	Study period	Group	Body height (SD) [cm]	Body weight (SD) [kg]	Exercise endurance time (SD) (min,sec) [' "]
Ding et al[8]	1980-1981	Boys	-	-	17'53" (2'43")
		Girls	-	-	14'21" (2'29")
Lin et al[9]	1989-1992	Boys	158.4 (6.7)	44.3 (5.8)	12'24" (1'15")
		Girls	156.3 (6.1)	43.5 (7.3)	10'45" (36")
Present report	1992	Boys	158.7 (8.1)	44.6 (8.1)	15'40" (2'12")
		Girls	155.5 (6.1)	46.4 (7.0)	13'18" (2'05")

and that Hong Kong children are fitter than their Beijing counterparts. A collaborative, larger-scaled, comparative study using exactly the same sampling method and test procedures would be desirable to clarify the situation.

In the early 1980s, an intensive study of the physical fitness profile for schoolchildren aged between 9 and 18 years was performed in Hong Kong and showed that the cardiopulmonary function of Hong Kong children was not as good as their counterparts in Thailand or Canada.[12] In that study, the Asian Council for the Standardization of Physical Fitness Test was used and the cardiopulmonary endurance was tested by an endurance run (1000 m for boys aged between 11 and 18 years, 800 m for girls of the same age-group, and 600 m for children younger than 11 years). A comparison between the treadmill test and endurance run for the evaluation of cardiopulmonary fitness has not been attempted and hence it cannot be ascertained which test is more representative of a child's cardiopulmonary fitness.

In conclusion, we assessed the physiological response to the treadmill test in normal 8- and 13-year-old children from middle and lower socio-economic backgrounds in Hong Kong and found that the 13-year-old children had better cardiopulmonary endurance. In the 8-year-old age-group, however, those with less body fat were fitter. A larger study is needed to establish the normal standards for children of different ages.

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