Peak oxygen uptake in healthy Chinese children and adolescents by age, sex, and maturation: abridged secondary publication

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KEY MESSAGES

1. There are developmentally divergent trajectories for peak oxygen uptake between Southern Chinese and Caucasian children and adolescents.
2. When body mass is appropriately accounted for, peak oxygen uptake is greater in boys than girls from age 13 years, increasing with age in males but not in females.
3. Population-specific references are important for proper interpretation of cardiopulmonary exercise test parameters.

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Introduction

Peak oxygen uptake (VO_2) is defined as the greatest oxygen uptake elicited in a maximal exercise test and is considered the best indicator of cardiopulmonary fitness. We aimed to develop peak VO_2 references by age, sex, and maturation for Hong Kong Chinese children and adolescents aged 8 to 16 years.

Methods

The study protocol was approved by the Joint Chinese University of Hong Kong – New Territories East Clinical Research Ethics Committee. Chinese children and adolescents aged 8 to 16 years were recruited from randomly selected primary and secondary schools from four geographical regions of Hong Kong. Those with acute or chronic illness or recent upper respiratory tract or other infection within the past 4 weeks were excluded. Participants were assessed at the cardiopulmonary exercise laboratory in the Prince of Wales Hospital.

Body weight and percentage body fat were measured using foot-to-foot bioelectrical impedance (TBF-401, Tanita, Tokyo, Japan). Height was measured to the nearest 0.5 cm with a Harpenden stadiometer (Holtain, Grymych, UK).[1] Participants were asked to choose the most appropriate stage that best indicated their own sexual maturity using the Tanner pubertal self-assessment questionnaire.

Cardiopulmonary fitness was assessed using a maximal treadmill running test.[2] Heart rate was monitored. Breath-by-breath gas samples were collected using a comfortably fitted facemask and analysed using the Medgraphics System CPX/DTM metabolic cart (Medical Graphics Corporation, St. Paul [MN], USA). Peak VO_2 was determined with standardised criteria.[1] Peak VO_2 ($L \cdot min^{-1}$) was ratio-scaled to body mass ($mL \cdot kg^{-1} \cdot min^{-1}$), fat-free mass ($mL \cdot kg\ FFM^{-1} \cdot min^{-1}$), and adjusted for body mass using an allometric model.

Participants were grouped according to age, sex, and maturation. Student's *t* test, Mann-Whitney *U* test, and Chi-square test were used for group comparisons for parametric, nonparametric, and categorical data, respectively. Group differences in peak VO_2 were compared using analysis of variance. The level of significance was set at 5%.

Percentile curves for log-linear-adjusted peak VO_2 (expressed in $L \cdot min^{-1}$) were constructed using the LMS method. The LMS method using the maximum penalised likelihood has been used to perform model fitting of the anthropometric centiles for the physical parameters.[3]

Results

Data from 852 children and adolescents aged 8 to 16 years were included in the final analyses (Table). Univariate analysis of variance showed that absolute peak VO_2 ($L \cdot min^{-1}$) differed by age ($P<0.001$), with a significant interaction ($P<0.001$). Follow-up analyses demonstrated an increase in absolute peak VO_2 ($L \cdot min^{-1}$) with age in both sexes. Pairwise comparisons confirmed that the difference in peak VO_2 ($L \cdot min^{-1}$) between boys and girls became apparent starting from age 12 years. When peak VO_2 was expressed as a ratio with body mass ($mL \cdot kg^{1} \cdot min^{-1}$), similar results were observed, with significant main effects for age ($P<0.001$) and sex ($P<0.001$) and a significant

TABLE. Descriptive characteristic of the children

Characteristic	Boys (n=410)*	Girls (n=442)*	P value
Age, y	12.5±2.4	12.5±2.4	>0.05
Height, cm	153.5±15.4	150.4±11.3	<0.001
Weight, kg	46.1±14.1	42.6±11.7	<0.001
Body mass index, kg/m^2	19.2±3.7	18.5±3.3	0.004
Body fat, %	18.8±7.9 (n=289)	21.0±7.6 (n=300)	0.001
Fat free mass, kg	37.3±11.0 (n=289)	32.7±6.9 (n=300)	<0.001
Resting heart rate	82±14	85±14	0.001
Peak heart rate	196±10	195±9	0.241
Peak oxygen uptake (L·min^{-1})	2.00±0.73	1.58±0.44	<0.001
Predicted peak oxygen uptake (L·min^{-1})†	2.26±0.56	1.80±0.29	<0.001
Fat free mass-adjusted peak oxygen uptake (mL·kg^1·min^{-1})	56.1±8.4 (n=289)	51.3±6.8 (n=300)	<0.001
Peak oxygen uptake (mL·kg^1·min^{-1})	43.4±8.4	37.8±6.7	<0.001
RERmax	1.12±0.08	1.09±0.09	<0.001

* Data are presented as mean ± standard deviation

† Based on regression equations[5]: peak VO_2 for boys = -0.623+0.230 × age; peak VO_2 for girls = 0.253+0.124 × age

interaction (P<0.001). Peak VO_2 (mL·kg^1·min^{-1}) increased with age in boys but remained relatively stable or slightly decreased in girls after age 10 years. Peak VO_2 (mL·kg^1·min^{-1}) became significant different between boys and girls from age 12 years onwards (P<0.001). When peak VO_2 values were compared using an allometric model, there was sex difference in adjusted peak VO_2 (mL·kg^1·min$^{-0.77}$) from age 13 years. Allometrically adjusted peak VO_2 increased with age in the boys only (P<0.001). There was no significant main effect for age in girls.

Regarding the development of peak VO_2 by maturational status, univariate analysis of variance showed that absolute peak VO_2 (L·min^{-1}) differed by Tanner stage (P<0.001) and sex (P<0.001), with a significant interaction (P<0.001). Boys had a significantly higher absolute peak VO_2 (L·min^{-1}) than girls within each Tanner stage. These differences were greatest in Tanner stages IV and V. When peak VO_2 was scaled allometrically to body mass (mL·kg^1·min$^{-0.77}$), there were significant main effects for Tanner stage (P<0.001) and sex (P<0.001), with a significant interaction (P<0.001). Pairwise comparisons confirmed that the difference in peak VO_2 (mL·kg^1·min$^{-0.77}$) between sexes was apparent from Tanner stage 2 onwards. The allometrically adjusted peak VO_2 increased significantly with maturational in boys from Tanner stage 4 (P<0.001) only. In girls, there was a decline in allometrically scaled peak VO_2 at Tanner stage 3, but no differences between Tanner stages 1 and 2 and between Tanner stages 4 and 5 (P>0.05).

Using the LMS method, percentile curves for absolute peak VO2 were constructed for boys and girls (Fig.).

Discussion

To the best of our knowledge, this is the only adequately powered study of treadmill-derived peak VO_2 of Hong Kong Chinese children and adolescents. Absolute peak VO_2 increased with age in both sexes, which is in accord with reports from elsewhere. When using an allometric model to account for differences in body mass, the adjusted peak VO_2 values from age 8 to 16 years were similar to previous work in Hong Kong Chinese boys[4] and Caucasian

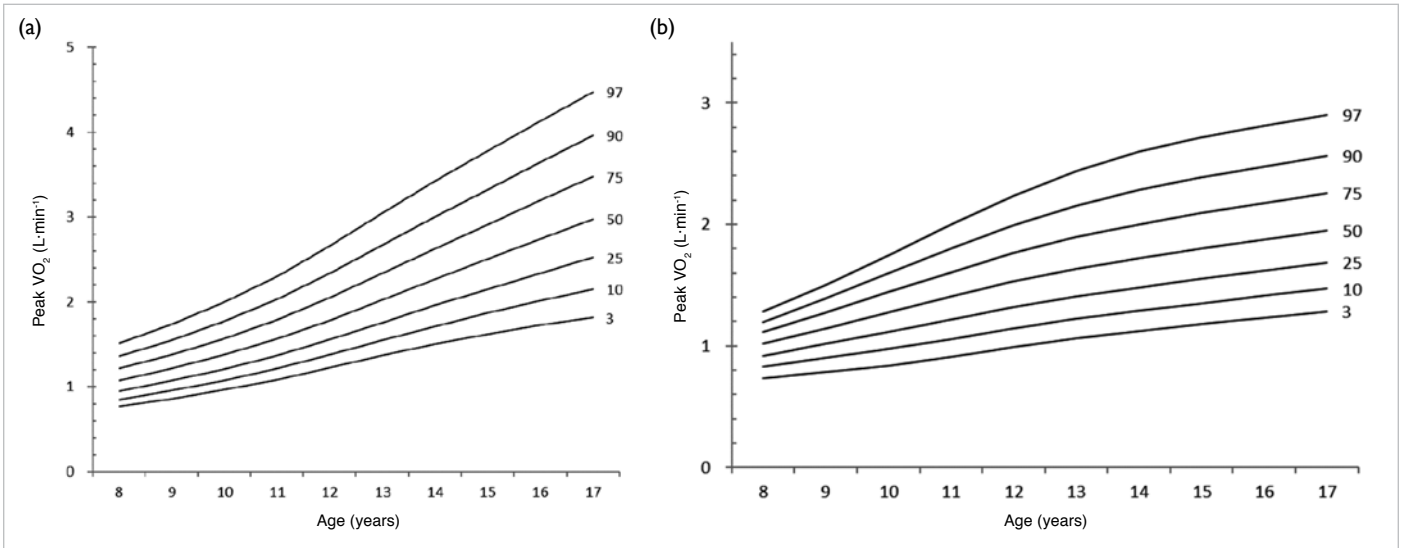

FIG. Centiles for peak VO_2 (L·min^{-1}) in (a) boys and (b) girls

boys, with a rise from age 13 years onwards. For girls, there was little variation in adjusted peak VO_2 across age. This is quite different from the pattern reported in Caucasian girls, who show a rise in peak VO_2 in early puberty, followed by a plateau.

Similar to previous studies, absolute peak VO_2 values were lower in girls than in boys. The difference in absolute and body mass–related peak VO_2 between boys and girls became significant from age 12 years, with the difference gradually widened as age increased. When an allometric model was applied, sex difference existed in adjusted peak VO_2 from age 13 years.

Compared to the predicted peak VO_2,[5] the absolute peak VO_2 values from our Hong Kong children are considerably lower than those for Caucasian children. It is possible that Southern Chinese children reach peak height velocity at an earlier age, and this results in less time available for prepubertal growth and developmentally divergent peak VO_2, compared with Caucasian children. Conventionally, peak VO_2 is expressed as a ratio standard with body mass. The developmental pattern of body mass–adjusted peak VO_2 declining with age in Hong Kong girls was similar to Caucasian girls and Northern Chinese girls. However, a different developmental pattern of body mass–adjusted peak VO_2 was observed in Hong Kong boys, with values remaining steady from age 8 to 12 years and gradually increased afterwards. This differs from observations in Northern Chinese boys that body mass–adjusted peak VO_2 increases from age 10 to 13 years and then remains steady. The theoretical and statistical limitations of the ratio standard to remove the effects of body mass have long been recognised. The use of allometric scaling removes the effects of body size and provides a better understanding of the actual developmental trajectory of peak VO_2. We confirmed that allometrically scaled peak VO_2 in girls did not decline with age.

We calculated reference values for absolute peak VO_2 using the LMS method for different age groups in boys and girls. The LMS method has been used for constructing similar centile curves in paediatric growth charts and reference ranges. These centile curves provide population-specific references for proper interpretation of peak VO_2 in Hong Kong Chinese children and adolescents.

Conclusion

There are developmentally divergent trajectories for peak VO_2 in Southern Chinese children and adolescents, compared with Caucasian children. When body mass is appropriately accounted for, peak VO_2 is greater in boys than girls from age 13 years, increasing with age in males but not in females. Moderate-to-vigorous physical activity is not related to allometrically scaled peak VO_2. With adjustment by fat free mass, peak VO_2 is not impaired in students who are centrally obese.

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Disclosure

The results of this research have been previously published in:
(1) Yu CCW, McManus AM, Au CT, et al. Appropriate scaling approach for evaluating peak VO2 development in Southern Chinese 8 to 16 years old. PLoS One 2019;14:e0213674.

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