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.

Introduction

Peak oxygen uptake (VO₂) 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 VO₂ 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, Grynmych, UK). 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. 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 VO₂ was determined with standardised criteria. Peak VO₂ (L·min⁻¹) was ratio-scaled to body mass (mL·kg⁻¹·min⁻¹), fat-free mass (mL·kg FFM⁻¹·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 VO₂ were compared using analysis of variance. The level of significance was set at 5%.

Percentile curves for log-linear-adjusted peak VO₂ (expressed in L·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.

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 VO₂ (L·min⁻¹) differed by age (P<0.001), with a significant interaction (P<0.001). Follow-up analyses demonstrated an increase in absolute peak VO₂ (L·min⁻¹) with age in both sexes. Pairwise comparisons confirmed that the difference in peak VO₂ (L·min⁻¹) between boys and girls became apparent starting from age 12 years. When peak VO₂ was expressed as a ratio with body mass (mL·kg⁻¹·min⁻¹), similar results were observed, with significant main effects for age (P<0.001) and sex (P<0.001) and a significant
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 VO$_2$ 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

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**TABLE.** Descriptive characteristic of the children

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

* 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

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**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 VO₂ across age. This is quite different from the pattern reported in Caucasian girls, who show a rise in peak VO₂ in early puberty, followed by a plateau.

Similar to previous studies, absolute peak VO₂ values were lower in girls than in boys. The difference in absolute and body mass–related peak VO₂ 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 VO₂ from age 13 years.

Compared to the predicted peak VO₂, the absolute peak VO₂ 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 result in less time available for prepubertal growth and developmentally divergent peak VO₂, compared with Caucasian children. Conventionally, peak VO₂ is expressed as a ratio standard with body mass. The developmental pattern of body mass–adjusted peak VO₂ 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 VO₂ 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 VO₂ 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 VO₂. We confirmed that allometrically scaled peak VO₂ in girls did not decline with age.

We calculated reference values for absolute peak VO₂ 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 VO₂ in Hong Kong Chinese children and adolescents.

**Conclusion**

There are developmentally divergent trajectories for peak VO₂ in Southern Chinese children and adolescents, compared with Caucasian children. When body mass is appropriately accounted for, peak VO₂ 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 VO₂. With adjustment by fat free mass, peak VO₂ is not impaired in students who are centrally obese.

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**Disclosure**

The results of this research have been previously published in:


**References**