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Gas Exchange Response to Exercise in Children\textsuperscript{1,2}

DAN M. COOPER\textsuperscript{1} and DANIEL WEILER-RAVELL

Introduction

The focus of exercise studies in children has historically been on the child's capacity to participate in sports and on the identification of potential athletes (1, 2, 3). More recently, there has been interest in exercise as a means of evaluating children with asthma, cystic fibrosis, and congenital heart disease (4, 5, 6). With the development of noninvasive techniques to analyze gas exchange during exercise breath-by-breath (7, 8) and, therefore, the tools to gain insight to the kinetics of the exercise response, the potential usefulness of exercise testing in the clinical setting is even greater. In this report, we present our evaluation of exercise testing using breath-by-breath techniques in a large population of children. We measured two parameters of the aerobic response to exercise. The first is the traditional "maximum oxygen uptake." We compared our results to the classic study of Åstrand done 30 years ago, in which oxygen uptake was measured by the Douglas bag method (1). The second is the noninvasive measurement of the anaerobic threshold. We used height as an index of body size because this has previously proved to be accurate in developing predictive equations in pulmonary function testing in children (9, 10).

Methods

Population

We tested 109 children, 51 girls and 58 boys, ranging in age from 6 to 17 yr. Both the boys and girls were equally distributed over this age range. Mean values of height, weight, and age are given in Table 1. Children were all volunteers from our community. No attempt was made to select children who were involved in rigorous sports or training programs. Obese children, children with a history of chronic disease of any organ system, or children who, for whatever reason, were not allowed to participate in physical education programs at school were excluded from the study. Eighty-six percent of the children were Caucasian; the remainder were oriental, Hispanic, and black. The children were predominantly of the middle socioeconomic class. This study was approved by the Human Subjects Committee of the Harbor-UCLA Medical Center, and informed consent was obtained from the children and their guardians.

Protocol

We used cycle ergometry and a continuously increasing work rate—ramp forcing function—developed in this laboratory (11). The children pedaled at 0 watts (W), unloaded cycling, for a warm-up period of 3 to 4 min; then the work rate increased until the limit of the subject's tolerance was reached. Each child maintained a constant pedaling rate of 50 to 70 rpm for the whole test period. The children were actively encouraged to "get to the top of the hill." The average test period was only 12 min.

Measurement of Gas Exchange

Breath-by-breath measurements of gas exchange were made using rapid gas analyzers (mass spectrometer) and pneumotachographs for flow and volume measurements (10). On-line display of ventilation (\(V_t\)), oxygen uptake (\(V_O_2\)), carbon dioxide output (\(V_CO_2\)), end-tidal \(P_O_2\) and \(P_CO_2\) (\(PETO_2\), \(PETCO_2\)), ventilatory equivalents of \(O_2\) and \(CO_2\) (\(VE/V_O_2\), \(VE/V_CO_2\)), and the gas exchange ratio (R) allowed us to measure the anaerobic threshold. This was taken as the point where hyperventilation with respect to \(V_O_2\), occurred without hyperventilation with respect to \(V_CO_2\). Thus, the AT was measured as the \(V_O_2\) where there was an abrupt increase in \(PETO_2\), \(VE/V_O_2\), and R with little or no change in \(PETCO_2\) and \(VE/V_CO_2\) (12). The maximal \(V_O_2\) (\(V_O_2,max\)) was taken as the greatest \(V_O_2\) achieved by the child during the exercise test.

RESULTS

In figures 1–4 we show the values of AT and \(V_O_2,max\) as a function of height. For both the \(V_O_2,max\) and the AT, girls had significantly lower values than the boys. The shaded areas in the figures represent the 95% confidence bands for the mean of our population. The outlined lines represent the 95% confidence bands for estimating AT from our population. See text and table 2 for linear regression equation, confidence band formulas, and correlation coefficient.

TABLE 1

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>MEAN HEIGHT, WEIGHT, AND AGE OF THE STUDY POPULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Height (cm) Mean ± 1 SD</td>
</tr>
<tr>
<td>Girls</td>
<td>51</td>
</tr>
<tr>
<td>Boys</td>
<td>58</td>
</tr>
<tr>
<td>All children</td>
<td>109</td>
</tr>
</tbody>
</table>

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Fig. 2. Left Panel: The anaerobic threshold (AT) as a function of height in normal boys, and (right panel) in normal girls. Hatched areas represent the 95% confidence bands for the mean of our population. The outlying lines represent the 95% confidence bands for estimating AT from our population. See text and table 2 for linear regression equations, confidence band formulas, and correlation coefficients.

Fig. 3. The maximal oxygen uptake (V\textsubscript{O\textsubscript{max}}) as a function of height in normal girls and boys. Hatched area represents the 95% confidence bands for the mean of our population. The outlying lines represent the 95% confidence bands for estimating V\textsubscript{O\textsubscript{max}} from our population. See text and table 3 for linear regression equations, confidence band formulas, and correlation coefficient.

Fig. 4. Left Panel: The maximal oxygen uptake (V\textsubscript{O\textsubscript{max}}) as a function of height in normal boys, and (right panel) in normal girls. Hatched areas represent the 95% confidence bands for the mean of our population. The outlying lines represent the 95% confidence bands for estimating V\textsubscript{O\textsubscript{max}} from our population. See text and table 3 for linear regression equations, confidence band formulas, and correlation coefficients.