Physical Fitness of Children Resident at High Altitude in Bolivia

N. Fellmann, J. Coudert, H. Spielvogel, M. Bedu, P. Obert, G. Falgairette, E. Van Praagh
Laboratory of Physiology and Sports Biology, Faculty of Medicine, 63001 Clermont-Ferrand, France
Instituto Boliviano de Biologia de Altura, La Paz, Bolivia

Abstract


In 7–15-yr-old children living in La Paz (Bolivia, altitude 3,700 m) (HA):

1) Maximal oxygen consumption (VO\textsubscript{2max}) varies from 35 to 45 ml \cdot min\textsuperscript{-1} \cdot kg\textsuperscript{-1} and maximal heart rate from 188 to 194 beats \cdot min\textsuperscript{-1}. These values are lower than those of their counterparts at low altitude (LA) by 10–20% and 10–15 \cdot min\textsuperscript{-1}, respectively.

2) The anaerobic metabolism is not affected by chronic hypoxia if the nutritional conditions and pubertal development of HA and LA boys are the same. When related to percent of VO\textsubscript{2max}, submaximal O\textsubscript{2} debts are similar at HA and LA. After supramaximal exercise, maximal O\textsubscript{2} debts (45.7 ± 2.7 vs 45.9 ± 3.8 ml \cdot kg\textsuperscript{-1}) and blood lactate concentrations (7.6 ± 0.6 vs 6.5 ± 0.6 mmol \cdot l\textsuperscript{-1}) are also the same at HA and LA. No differences are observed between the 2 altitudes in ventilatory (60 vs 56% VO\textsubscript{2max}) and lactate (60 vs 65% VO\textsubscript{2max}) thresholds. The altitude of La Paz does not alter the anaerobic performance of a force-velocity test (from 6 to 10 W \cdot kg\textsuperscript{-1}) between the ages of 7 to 15 years but reduces by 14–17% the mean anaerobic power developed during a 30-s Wingate test. This decrease could be linked to a lower participation of glycolysis and aerobic metabolism at HA during this test.

3) Poor socio-economic and nutritional conditions do not modify the aerobic performance of boys living in La Paz but lead to lower maximal anaerobic power (from 17% to 25%) when compared with HA boys from a high socio-economic background.

4) Finally, the altitude of La Paz does not change the development of aerobic and anaerobic metabolisms during puberty.

Key words

Maximal oxygen consumption, anaerobic metabolism, malnutrition, puberty development

Introduction

In contrast to adults, little information is available on the effect of chronic hypobaric hypoxia on children's work capacity. Barring one study on Ethiopian boys residing at an altitude of 3,000 m (1), all the other investigations are focused on children resident in the Andes at altitudes of 3,500 m–4,000 m in La Paz (Bolivia).

Some considerations must be stated for a clear interpretation of the results:

1) Due to considerable interbreeding, it is very difficult to define accurately the genetic background of children. Ethnic background in South America is often associated with socio-economic status. The Aymara boys are of a low socio-economic class and those with Spanish ancestry are from middle and upper-class families. These genetic and social differences affect the nutritional conditions and can alter the physical capacities of the boys.

2) Therefore, comparisons with children living at low altitude are not easy to establish. Generally, high altitude residents are compared with groups from Caucasian families of a high socio-economic class, living at low altitude under various climates and socio-cultural conditions.

3) To our knowledge, no report exists on the histological and enzymatic muscle studies in high altitude resident children.

The aim of this study is: 1) to summarize the literature data on the physical capacities of children living in La Paz (HA) and to compare their performances with those of their counterparts living at low altitude (LA), 2) and to analyse if the alterations observed in children are the same as in adults living under the same environmental conditions.

I. Aerobic Performance

By direct method, using treadmill or cycle ergometer, the maximal oxygen consumption (VO\textsubscript{2max}) of untrained children living in La Paz varies from 35 to 45 ml \cdot min\textsuperscript{-1} \cdot kg\textsuperscript{-1} according to the studies (7, 8, 11, 13) (see Figure 1). These values are of the same order of magnitude as found by Andersen (1) in 10–12-yr-old Ethiopian boys living at an altitude of 3,000 m (40 ml \cdot min\textsuperscript{-1} \cdot kg\textsuperscript{-1}).

At HA, VO\textsubscript{2max} is reduced by 10–20% when compared with mean values in untrained LA children of the same age and socio-economic class, and from Amerindian or European families. A similar VO\textsubscript{2max} decrease has been reported by Raynaud et al. (20) in adult men living in La Paz.
at high altitude and 33 born at low altitude who migrated to La Paz between the age of 6 and 11 years (11).

A chronic marginal malnutrition has no influence on aerobic performance. No difference is observed between European boys from middle and upper-class families and Aymara boys (13). More recently, we found in La Paz that 11-yr-old boys from a poor socio-economic background exhibited a lower VO2max (in l min⁻¹) than HA rich boys. However this VO2max decrease is due to a diminished muscle mass since the difference is eliminated when VO2max is expressed in ml min⁻¹ kg⁻¹ muscle weight. The same result is found at LA in the tropical area of Santa Cruz de la Sierra (Bolivia, 500 m)(18).

At the present time, there is no evidence in children to explain the decrease in VO2max at HA, from adults’ data, the limiting factor could be the O₂ diffusion in muscle. The decrease in O₂ pressure gradient between capillaries and mitochondria (linked to the PaO₂ reduction) may induce a lower VO2max at HA (21).

II. Anaerobic Performance

Till now, the anaerobic metabolism of HA children has been only investigated by our team in collaboration with the members of the “Instituto Boliviano de Biología de Altura” in La Paz.

The anaerobic metabolism evaluated by submaximal and maximal O₂ debts, blood lactate concentrations after maximal or supramaximal exercises, anaerobic ventilatory and lactate thresholds and maximal anaerobic power is not different between children living in La Paz and European or Bolivian children at LA (Table 1). However this is only true if the 2 groups belong to the same socio-economic backgrounds and have the same level of sexual maturation.

O2 Debt (Table 1)

When related to % VO2max, the O₂ debt of 50 boys and girls aged 10 to 13 yrs, born and living in La Paz or residing for 3 yrs or more at HA, is similar to that of 25 French children at LA (7). In particular, maximal O₂ debts obtained after exercises of 115% maximal aerobic power intensity are the same at HA and LA (Table 1). These values correspond to literature data for untrained children of the same age living at LA (19). Moreover, VO2 kinetics during recovery are also the same at HA and LA, consistent with previous findings in adults acclimatized to La Paz altitude (20).

Blood lactate concentration ([L])

No difference is observed between HA and LA for [L] after maximal exercise (6.0 ± 0.3 vs 6.7 ± 0.5 mmol. l⁻¹) and supramaximal exercise (Table 1), and for linear relationships between maximal O₂ debit and [L] (7).

However the interpretation of anaerobic data must take into account the sexual maturation of the children compared. Indeed, [L] is higher in 12-yr-old boys at HA than in LA boys of the same chronological age but with delayed gonadal development (8).
Table 1  Data on anaerobic metabolism in boys from a high socio-economic background living at high altitude (La Paz, 3,700 m) (references 2, 6, 7).

<table>
<thead>
<tr>
<th>Tests</th>
<th>Units</th>
<th>High Altitude boys (La Paz, 3,700 m)</th>
<th>Low Altitude boys (France, 330 m)</th>
<th>Significance</th>
<th>Age yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supramaximal exercise (115% MAP)</td>
<td>Maximal O2 debt [L]</td>
<td>1.64 ± 0.14</td>
<td>1.73 ± 0.16</td>
<td>NS</td>
<td>10–13</td>
</tr>
<tr>
<td></td>
<td>Ventilatory threshold</td>
<td>1.01 ± 0.04</td>
<td>1.32 ± 0.07</td>
<td>2, 7, 11</td>
<td>11–13</td>
</tr>
<tr>
<td></td>
<td>Lactate threshold</td>
<td>0.92 ± 0.04</td>
<td>1.14 ± 0.03 NS</td>
<td>7–8</td>
<td></td>
</tr>
<tr>
<td>Maximal Exercise</td>
<td>W·kg⁻¹·BW</td>
<td>6.0 ± 0.6</td>
<td>5.9 ± 1.2</td>
<td>NS</td>
<td>7–8</td>
</tr>
<tr>
<td>Force Velocity test</td>
<td>W·kg⁻¹·BW</td>
<td>4.1 ± 0.9</td>
<td>4.6 ± 1.1</td>
<td>NS</td>
<td>7–8</td>
</tr>
<tr>
<td>30-s Wingate test</td>
<td>VO₂ [L]</td>
<td>309 ± 63</td>
<td>363 ± 90</td>
<td>NS</td>
<td>7–8</td>
</tr>
<tr>
<td></td>
<td>ml STPD</td>
<td>452 ± 84</td>
<td>587 ± 83</td>
<td>2, 6, 7</td>
<td>11–12</td>
</tr>
<tr>
<td></td>
<td>mmol·l⁻¹</td>
<td>3.4 ± 1.5</td>
<td>6.5 ± 2.2</td>
<td>2, 6, 7</td>
<td>11–12</td>
</tr>
</tbody>
</table>

Values are means ± SE. MAP: maximal aerobic power; BW: body weight; [L]: blood lactate concentration. Comparisons between high and low altitude boys are: NS: non significant; *p < 0.05; **p < 0.01; ***p < 0.001

**Anaerobic thresholds**

Although VO₂ at ventilatory (VT) and lactate (LT) thresholds are lower at HA, VT and LT are the same at both altitudes when related to % VO₂max (6) (Table 1).

**Maximal anaerobic power**

The comparison between 47 boys in La Paz of a high socio-economical status and 101 French children at LA indicates that maximal mechanical anaerobic power developed during a force-velocity test is the same in HA and LA boys 7–15 yrs of age (2) (Table 1). These data are in line with findings in adults during acute (15) or chronic (9) hypoxia or during the acclimatization period (4, 17). All these results give further evidence that phosphagen stores which provide most of the energy during this test and creatine-kinase activities are probably not altered by high altitude in children as in adults (14, 16).

On the contrary, the “mean power” and the “peak power” developed during a 30-s Wingate test are reduced at HA by 14–17% from the ages 10–11 up to 15 (2) (Table 1). Two possible explanations for the decrease in Wingate performance at HA have been suggested. VO₂ during the 30-s test is reduced in HA boys by 17–20%, which is close to the reduction in VO₂max usually observed at this altitude (Table 1). Since the relative energy contribution of aerobic metabolism during a Wingate test is high, particularly in children, a reduced aerobic performance at HA can contribute to a lower performance during the Wingate test. The decrease in power can also be linked to a reduced participation of glycolysis at HA suggested by lower [L] after the test (Table 1).

As for VO₂max, changes during growth of anaerobic power developed during the 2 tests are the same at HA and LA i.e. a mean increase of 70% between 7 to 15 yrs (2).

In contrast to aerobic performance, marginally undernourished boys, living in poor districts of La Paz, developed during short-term intense exercises lower power than well nourished children from a high socio-economic background and living at the same altitude (18). These results and those for VO₂max strengthen previous findings in adults after hypocaloric diet under normoxic conditions. Russel et al. (22) found that the size of the slow-twitch fibres in calf and thigh muscles is better preserved than that of the fast fibres.

In conclusion, when compared with LA children, children resident in La Paz (3,700 m) have: a reduced aerobic performance by 10–20%, an unaltered anaerobic metabolism if the nutritional conditions and the level of sexual maturation are the same, and finally a similar development between the ages of 7 and 15 yrs for both metabolisms.

**References**


