Effect of Chronic Hypoxia and Socioeconomic Status on the Maximal Oxygen Uptake of 10- to 12-Year-Old Bolivian Boys

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Abstract

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The aim of this study was to analyze the effect of altitude and socioeconomic status on the maximal oxygen uptake ($\dot{V}O_2max$) of prepubertal Bolivian boys. The subjects were 143 prepubertal boys (10 to 11.5 years old) living in La Paz (altitude 3600 m, n = 67) and Santa Cruz de la Sierra (altitude 420 m, n = 76). At high altitude, 23 boys were from a high socioeconomic status (HAHSES) and 44 from a low socioeconomic background (HALSES). At low altitude, 29 boys were from a high socioeconomic level (LAHSES) and 47 from a low socioeconomic background (LALSES). Anthropometric characteristics were determined in order to assess the physical growth of the boys. The $\dot{V}O_2max$ was determined from a progressive maximal exercise (direct method). The subjects performed this test using the same cycle ergometer at both high and low altitudes.

For the overall anthropometric parameters, there was no significant difference between highland and lowland boys of the same socioeconomic status. However, regardless of altitude, boys from a low socioeconomic background were 2 years behind those from a high socioeconomic background. There was no significant difference for $\dot{V}O_2max$ between boys from high and low socioeconomic backgrounds at HA (HAHSES: 37.2 ± 5.6; HALSES: 38.9 ± 6.4 $ml \cdot min^{-1} \cdot kg^{-1}$ body weight) and at LA (LAHSES: 42.6 ± 5.4; LALSES: 43.1 ± 4.9 $ml \cdot min^{-1} \cdot kg^{-1}$ body weight). The $\dot{V}O_2max$ of highland boys was, on average, 11 % lower than that of lowland boys. It appears, therefore, that a difference in socioeconomic status has no effect on the $\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$) of prepubertal children at low altitude as well as the altitude of 3600 m.

Key words

Altitude, maximal oxygen uptake, prepubertal boys, malnutrition

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Introduction

Lowland residents, during both acute and chronic high altitude exposures, present a marked decrease in their maximal oxygen uptake (9, 19). This well-known phenomenon is due to the decrease in oxygen availability which results from the reduction in ambient oxygen pressure at higher elevations. Long-term residents and natives of high altitude, however, are not as negatively impaired. In fact, numerous studies have shown that the maximal oxygen uptake ($\dot{V}O_2max$) of highland adult natives was only slightly lower than that of lowland adult natives when both groups were studied in their own environment (4, 8). According to Mazess (21) and Frisancho (14), the highland population is adapted to the hypoxic stress and this adaptation is achieved by exposure to hypobaric hypoxia during growth and development. Most studies are however realized on adults and far less information is available for children. Several studies from our laboratory (7, 11–13) have shown that the $\dot{V}O_2max$ of well-nourished boys living in La Paz, Bolivia (3600 m) was 12 %–22 % lower than that of their lowland counterparts living in Clermont-Ferrand, France (330 m). Greksa et al. (16) in adolescent Bolivian swimmers and Andersen (2) in Ethiopian boys found similar results. These studies were however realized in well-nourished boys of high socioeconomic status. To our knowledge, there is no report on boys living at high altitude under poor socioeconomic conditions.

Studies realized at low altitude on subjects living in poor environmental and nutritional conditions have shown that, when biometric characteristics are taken into account, the $\dot{V}O_2max$ was markedly depressed in cases of severe malnutrition (6) but not modified in cases of marginal malnutrition (5, 28, 29, 30). Thus, it is of interest to verify if this is also true at high altitude.

The aim of the present work was therefore to study the effect of altitude and socioeconomic and nutritional conditions on the $\dot{V}O_2max$ of Bolivian boys.

Method

Subjects

143 prepubertal boys (10–11.5 years) took part in the present study:

23 boys living at HA and of high socioeconomic status (HAHSES)
44 boys living at HA and of low socioeconomic status (HALSES)
47 boys living at LA and of high socioeconomic status (LAHSES)
29 boys living at LA and of low socioeconomic status (LALSES)

Experimental procedure

The maximal oxygen uptake ($\dot{V}O_2max$) was determined by the direct method. The exercise bouts were conducted on a cycle ergometer of which the seat height, the handlebars and pedal crank were adjusted to child size. The pedaling frequency was maintained at 70 rpm and heart rate (HR) was recorded on an electrocardiogram. The subjects performed 3 to 4 successive 2-min 30-s steps against increasing braking forces until exhaustion. The first step began at a work load of 17.5 W and then the exercise intensity was increased by 17.5 W at each step. During the last 30 s of each step, samples of expired air were collected in Douglas bags. The volumes were measured with a Tissot spirometer. The fractions of O_2 and CO_2 in expired air were determined with a Servomex 570 A and a Capnograph Gould Mark III at both high and low altitudes. Analyzers were calibrated before each experimentation using standard gas mixtures. We included in the study only the data of boys from whom criteria of maximal aerobic power were achieved: actual exhaustion of the boys, respiratory gas exchange ratio (R) above the unit, and maximal heart rate (HR max) close to the maximum value which differed according to the altitude of residence.

Statistical analyses

The statistical analyses were realized on a Macintosh Classic computer. The data are expressed as means and standard deviations. The effects of socioeconomic status (SES) and altitude (A) were tested for by using two-way analysis of variance (ANOVA, Stat View SE + graphics package program). Statistical significance was chosen as $p < 0.05$.

Results

Anthropometric characteristics

For the overall body dimensions, there was a highly significant effect ($p < 0.001$) of socioeconomic status with boys of the HSES groups having higher body height (9 cm), body weight (5–7 kg), and lean body mass (3–4 kg) than the LSES groups. There were however no effect of altitude and no statistically significant interactions between A and SES.

Bioenergetic characteristics

The bioenergetic characteristics of the boys are presented in Table **1**. For $\dot{V}O_2max$ ($l \cdot min^{-1}$ STPD), there was a significant effect of altitude and socioeconomic status and no statistically significant interactions between A and SES. However, when $\dot{V}O_2max$ was expressed per kg of body weight ($ml \cdot min^{-1} \cdot kg^{-1}$ BW) or lean body mass ($ml \cdot min^{-1} \cdot kg^{-1}$ LBM), there was a highly significant effect of altitude but no effect of socioeconomic status and no statistically significant interactions between A and SES. The differences between HA and LA boys were 12.6 % for the HSES groups and 9.8 % for the LSES groups as regards to $\dot{V}O_2max$ in $ml \cdot min^{-1} \cdot kg^{-1}$ BW and 11.3 % for the HSES groups and 10.9 % for the LSES groups as regards to $\dot{V}O_2max$ in $ml \cdot min^{-1} \cdot kg^{-1}$ LBM.

In the same way, there was a highly significant effect of altitude but no effect of socioeconomic status and no statistically significant interactions between A and SES for minute ventilation ($\dot{V}E$) in absolute values and per body area. Similar results were obtained for R: at HA lower R values were reached than at LA.

Finally, for HR max, there was a significant effect of altitude and socioeconomic status and no statistically significant interactions between A and SES. The HR max of the highland boys was 7 $beats \cdot min^{-1}$ for the HSES groups and 6 $beats \cdot min^{-1}$ for the LSES groups lower than that of their lowland counterparts.

Discussion

Numerous studies realized in developing countries have shown that poor socioeconomic and hygienic conditions result in children with a high incidence of undernutrition which is largely marginal in degree, particularly among the school-aged population. The consequence of such conditions is a delay observed in the physical growth (1,20,27). A nutritional evaluation of the boys of the present study was realized from biometric characteristics by Spielvogel et al. (26). The results showed that boys living in poor socioeconomic and hygienic conditions (HALSES, LALSES) were approximately 2 years behind their well-to-do counterparts of the same age (HAHSES, LAHSES). In fact, boys of HAHSES and LAHSES groups were considered as well-nourished and boys of HALSES and LALSES groups as having marginal nutritional status. The marginal nutritional status of HALSES and LALSES boys is also confirmed by the results of biochemical analyses realized among our samples and presented elsewhere. Finally, dietary information obtained by Post et al. (22) showed that mean energy and nutrient (protein, fat, carbohydrate) intake were marginal in boys of HALSES and LALSES groups.

The most important feature of this study is that the maximal oxygen uptake of prepubertal boys living at LA as well as at an altitude of 3600 m is not altered by a marginal nutritional status. There was in fact no significant difference at HA as well as at LA between HSES and LSES groups for $\dot{V}O_2max$ in $ml \cdot min^{-1} \cdot kg^{-1}$ BW or BFM (Table **1**).

The results obtained in the present study at LA are in line with those observed in marginally undernourished lowland Colombian boys (5,28,29) and in young lowland Guatemalan adults from a low socioeconomic background (30). These studies have shown in fact that the $\dot{V}O_2max$ (in $l \cdot min^{-1}$) of well-nourished subjects was higher than that of marginally undernourished subjects and that the difference was eliminated when $\dot{V}O_2max$ was expressed per kg of BW or LBM. Similarly, at LA, Areskog et al. (3) in 10- to 13-year-old Ethiopian boys and Satyanarayana et al. (24) in 14- to 17-year-old Indian adolescents have shown that the PWC_{170} (18) of the well-nourished subjects, corrected for BW or LBM, was not different to that of the marginally undernourished subjects. When compared with the literature data, the $\dot{V}O_2max$ of LAHSES and LALSES boys were lower than those obtained by Spurr (28,29) in well-nourished and marginally undernourished Colombian boys (51–55 vs 43 $ml \cdot min^{-1} \cdot kg^{-1}$ BW). This difference may be due to the very poor level of physical fitness of the LAHSES and LALSES boys. Santa Cruz de la Sierra is located in a tropical zone. It enjoys a very hot and humid climate for 9 months of the year. These ambient conditions may lead to a reduction in voluntary physical activity among these children, which could explain their very poor physical fitness. The results obtained at HA cannot be compared with other studies. In fact, to our

Table 1 Bioenergetic characteristics of the boys.

	HA HSES n = 23	HA LSES n = 44	LA HSES n = 47	LA LSES n = 29	2-way ANOVA probability
$\dot{V}O_2max$ ($l \cdot min^{-1}$) STPD	1.36 ± 0.28	1.15 ± 0.23	1.48 ± 0.18	1.27 ± 0.10	A: < 0.05 SES: < 0.001 A × SES: NS
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$ BW) STPD	37.2 ± 5.6	38.9 ± 6.4	42.6 ± 5.4	43.1 ± 4.9	A: < 0.001 SES: NS A × SES: NS
$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$ LBM) STPD	47.4 ± 6.3	46.7 ± 7.5	53.4 ± 6.0	52.4 ± 5.1	A: < 0.001 SES: NS A × SES: NS
$\dot{V}E$ ($l \cdot min^{-1}$) BTPS	73.5 ± 10.1	68.1 ± 13.2	65.3 ± 10.9	58.2 ± 7.3	A: < 0.001 SES: < 0.01 A × SES: NS
$\dot{V}E$ ($l \cdot min^{-1} \cdot m^{-2}$ BA) BTPS	61.4 ± 6.7	65.4 ± 11.9	55.6 ± 9.4	55.9 ± 5.6	A: < 0.001 SES: NS A × SES: NS
HR max (beats $\cdot min^{-1}$)	190 ± 5	184 ± 12	197 ± 7	190 ± 10	A: < 0.001 SES: < 0.001 A × SES: NS
R	1.02 ± 0.11	1.05 ± 0.11	1.12 ± 0.06	1.10 ± 0.07	A: < 0.001 SES: NS A × SES: NS

Values are means ± SD; n = number of subjects; HA = high altitude; LA = low altitude; HSES = high socioeconomic status; LSES = low socioeconomic status; $\dot{V}O_2max$ = maximal oxygen uptake; BW = body weight; LBM = lean body mass; BA = body area; $\dot{V}E$ = minute ventilation; HRmax = maximal heart rate; R = respiratory exchange ratio; ANOVA = analysis of variance; A = altitude; SES = socioeconomic status; NS = not statistically significant.

knowledge, until now, no report exists on the $\dot{V}O_2max$ of marginally undernourished boys living at HA. Greksa et al. (17) studied in La Paz 11- to 12-year-old Aymara boys from a low socioeconomic background. However, these boys were considered as healthy and well-nourished. The $\dot{V}O_2max$ of the HAHSES boys was slightly lower than that of well-to-do boys previously studied by our team in La Paz (11,12,13). The discrepancy might be due to a difference in levels of physical fitness. In summary, it appears that at HA as well as at LA, the reduction in the physical work capacity ($\dot{V}O_2max$, PWC_{170}) of a marginally nourished boy is due to a reduction in his body weight and principally in his muscle mass. This decrease in muscle mass could be due to a reduction in the muscle fiber diameter and principally in the type II fiber diameter, the type I fiber diameter being far less decreased. In fact, Goldspink (15) has shown that in response to starvation in rats, muscles with a high proportion of slow-twitch fibers were less atrophied than those with a high proportion of fast-twitch fibers. Schantz et al. (25) showed that in normal subjects, a 2-week hypoenergetic diet resulted in a reduction in the size of the fast-twitch fibers of the triceps brachii and quadriceps femoris muscles, but the size of the slow-twitch fibers was not affected. In line with the results are the findings of Russell et al. (23) in fasting patients and of Essen et al. (10) in patients with anorexia nervosa. They found that the size of the slow-twitch fibers in the human calf and thigh muscles, respectively, was better preserved than that of the fast-twitch fibers. Russell et al. (23) even reported a fast-to-slow fiber transformation in obese subjects after hypocaloric dieting and fasting, but there is no evidence at the present time that this occurs as a consequence of long-term energy deficiency.

The second feature of this study is that an altitude of 3600 m induces a reduction in the maximum aerobic power of children. In fact, irrespective of the socioeconomic class, the $\dot{V}O_2max$ of HA boys was on average 11 % lower than that of their LA counterparts (Table **1**). Similar results were obtained previously by Bedu et al. (7) and Fellmann et al. (11–13) in untrained well-nourished boys and by Greksa et al. (16) between adolescent swimmers trained in La Paz and selected samples of sea level athletes.

In conclusion, it appears that a LSES results in lower $\dot{V}O_2max$ ($l \cdot min^{-1}$) which is primarily due to a reduction in body composition (principally muscle mass). This phenomenon was observed at LA as well as at HA (3600 m). Such an altitude induces a reduction of $\dot{V}O_2max$ which is in the same order (approximately 11 %) for well-nourished and marginally nourished boys.

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The Nutritional Intake of Bolivian Boys

The Relation Between Altitude and Socioeconomic Status

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Abstract

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The nutrition of 57 native Bolivian boys living at high altitude (HA) in La Paz (±4000 m) and of 63 boys living at low altitude (LA) in St. Cruz (±400 m) is described. The dietary information was obtained with a 24-h recall method, by interviewing the child and mother. The food items are listed in household measures and weight if possible. All food items were converted into grams, and nutrients were calculated by using food composition tables of Latin America.

The results show that the energy and nutrient intake of the HSES boys was significantly higher ($p < 0.05$) than the intake of the LSES boys, at both altitudes. At HA the mean energy intake of the HSES boys was about 9.8 MJ per day (±0.7); for the LSES boys an intake was found of 8.4 MJ per day (±0.4). At LA the HSES boys had an energy intake of 10.7 MJ per day (±0.6) and the LSES boys 7.7 MJ per day (±0.3). The daily protein intake was in HAHSES boys 85 g (±8), LAHSES 100 g (±8), HALSES 60 g (±4), and LALSES 52 g (±3). In comparison with the recommended daily requirements the dietary intakes of the HSES boys seem too "rich," and of the LSES boys to some extent too "poor." These results are reflected in smaller body height and body weight of LSES boys and a higher fat mass in HSES boys irrespective of altitude.

Key words

Nutrition, Bolivia, schoolboys, prepubertal, altitude, socioeconomic status

Introduction

Altitude and socioeconomic status of the family are seen as major factors affecting childhood growth (23, 28). The growth pattern of any population cannot be viewed as the result of only environmental factors; it is an end product of the interaction of many factors such as genetic background, nutritional status, disease, stress, and hypoxia at high altitude. During childhood and adolescence, children with similar genetic backgrounds, but different nutritional status, show differences in height; on the other hand, children of different genetic backgrounds and similar nutritional status also show differences in height (8,12,18,25). The fact that adolescents of poor nutritional status are significantly shorter than their counterparts of good nutritional status indicates that under conditions of poor nutrition the role of genetic factors on growth in height can be overridden by the influence of environmental factors (4). On the other hand, nutritional status in less developed countries is strongly influenced by the socioeconomic status of the family.

It is interesting to determine if a lifestyle factor, such as nutrition, is related to health factors such as growth of prepubertal boys, if living at high altitude may influence these factors, and if indeed socioeconomic level has its effect in another way.

This article presents the nutrition of native highland and lowland Bolivian boys, 10- to 12-years-old, living in urban La Paz and Santa Cruz de la Sierra.

Subjects and Methods

Subjects

The study included 120 boys ranging in age from 10- to 12-years (mostly derived from birth certificates).

In La Paz, at high alttitude (HA), a sample of 57 boys was examined in relation to nutrition; 17 boys from high socioeconomic status (HSES) and 40 boys of low socioeconomic status (LSES). In Santa Cruz, at low altitude (LA), the dietary intake of a sample of 63 boys was studied; 23 boys of HSES and 40 boys of LSES.

Nutritional interview

In order to choose the right method for determining the nutritional intake, the following factors had to be considered:

- During the months of July and August about 4 weeks were available to collect data.
- One local nutritionist was available during the study period.
- The expected variance in food items.

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