Effect of chronic hypoxia and socioeconomic status on $\dot{V}O_{2\,max}$ and anaerobic power of Bolivian boys

PHILIPPE OBERT, MARIO BEDU, NICOLE FELLMANN, GUY FALGAIRETTE, BRUNO BEAUNE, AÏDA QUINTELA, EMMANUEL VAN PRAAGH, HILDE SPIELVOGEL, HAN KEMPER, BERTHEKE POST, GÉRARD PARENT, AND JEAN COUDERT
Laboratoire de la Performance Motrice, UFRSTAPS, 63170 Aubière; Laboratoire de Physiologie, Faculté de Médecine, 63001 Clermont-Ferrand, France; ORSTOM/Instituto Boliviano de Biología de Altura, Casilla 717, La Paz, Bolivia; and Department of Health Science, Faculty of Human Movement Sciences, AMC Meibergdreef 15, 1105 AZ Amsterdam, The Netherlands

OBERT, PHILIPPE, MARIO BEDU, NICOLE FELLMANN, GUY FALGAIRETTE, BRUNO BEAUNE, AÏDA QUINTELA, EMMANUEL VAN PRAAGH, HILDE SPIELVOGEL, HAN KEMPER, BERTHEKE POST, GÉRARD PARENT, AND JEAN COUDERT. *Effect of chronic hypoxia and socioeconomic status on $\dot{V}O_{2\,max}$ and anaerobic power of Bolivian boys.* J. Appl. Physiol. 74(2): 888–896, 1993.—The aim of this work was to analyze the effects of altitude and socioeconomic and nutritional status on maximal oxygen uptake ($\dot{V}O_{2\,max}$) and anaerobic power (P) in 11-yr-old Bolivian boys. At both high (HA) (3,600 m) and low (LA) (420 m) altitudes, the boys were divided into high (HA_1, n = 23, LA_1, n = 48) and low (HA_2, n = 44, LA_2, n = 30) socioeconomic levels. Anthropometric characteristics, $\dot{V}O_{2\,max}$, and P [maximal P (Pmax) during a force-velocity test and mean P ($\bar{P}$) during a 30-s Wingate test] were measured. Results showed that *1*) anthropometric parameters were not different between HA_1 and LA_1 and HA_2 and LA_2 boys, but HA_2 and LA_2 boys were two years behind HA_1 and LA_1 boys in development; *2*) $\dot{V}O_{2\,max}$ was not different in boys from the same altitude, but at HA $\dot{V}O_{2\,max}$ was 10% lower than at LA (HA_1 = 37.2 ± 5.6, HA_2 = 38.9 ± 6.4, LA_1 = 42.5 ± 5.8, LA_2 = 42.5 ± 5.3 ml · min^{-1} · kg^{-1} body wt); and *3*) Pmax and $\bar{P}$ were higher in well-nourished than in undernourished boys, but there was no difference in Pmax and $\bar{P}$ between HA_1 and LA_1 and HA_2 and LA_2 boys (HA_1 = 6.8 ± 1.0, HA_2 = 5.5 ± 0.8, LA_1 = 7.1 ± 1.0, LA_2 = 5.3 ± 0.9 W/kg for Pmax; HA_1 = 5.2 ± 0.8, HA_2 = 4.5 ± 0.9, LA_1 = 5.2 ± 0.7, LA_2 = 4.0 ± 0.6 W/kg for $\bar{P}$). A marginal state of malnutrition had no effect on $\dot{V}O_{2\,max}$ but led to lower P in prepubertal children at HA as well as at LA.

aerobic metabolism; force-velocity test; Wingate test; prepubertal boys; malnutrition

---

THE DECREASE IN MAXIMUM AEROBIC POWER ($\dot{V}O_{2\,max}$) of lowland residents, during both acute and chronic high altitude (HA) exposures, is well recognized (9) and is related to the decrease in oxygen availability, which is a result of the reduction in ambient oxygen pressure at higher elevations. Long-term HA residents and natives, however, are not as negatively impaired. In fact, several studies have shown that $\dot{V}O_{2\,max}$ of HA adult natives was only slightly lower than that of adult natives living at sea level when both groups were studied in their own environment (4, 10). Mazess (34) and Frisancho et al. (20) have suggested that the highland population was adapted to the hypoxic environment and that this adaptation was achieved by exposure to hypobaric hypoxia during growth and development. Most studies are, however, conducted with adults and far less information is available on children. Studies from our laboratory (7, 18, 19) have shown that $\dot{V}O_{2\,max}$ of well-nourished boys living in La Paz, Bolivia (3,600 m), was 12–22% lower than that of their lowland counterparts living in Clermont-Ferrand, France (330 m). Similar results were obtained by Greksa et al. (25) with adolescent Bolivian swimmers and by Andersen (2) with Ethiopian boys. These studies were, however, performed with well-nourished boys from a high socioeconomic background. To our knowledge, no report exists on boys living at HA under poor socioeconomic and nutritional conditions. Studies conducted at low altitude (LA) on subjects living in poor environmental and nutritional conditions have shown that when body dimensions are taken into account, $\dot{V}O_{2\,max}$ is markedly depressed in cases of severe malnutrition (5) but is not modified in cases of marginal malnutrition (6, 44, 46, 50). Thus, it is of interest to verify whether this is also true at HA.

There is little information available concerning the influence of altitude on the anaerobic metabolism of children. We previously showed in our laboratory that anaerobic metabolism, evaluated by oxygen debt and blood lactate concentration after maximal and supramaximal exercises, was not modified by chronic hypoxia in young boys (18, 19). Moreover, we studied the anaerobic metabolism of boys from 7 to 15 yr by means of the external mechanical power developed during a force-velocity test and a Wingate test (7). We showed that an altitude of 3,600 m did not affect the performance during the force-velocity test but reduced that during the Wingate test. However, these studies covered well-nourished boys from a high socioeconomic background, and the lowland boys (control group) were of different ethnic (European) origins. At the present time, no information is available concerning the influence of altitude on the anaerobic metabolism of children from a poor socioeconomic background. Similarly, there are no data regarding the effect of reduced socioeconomic and nutritional conditions on anaerobic power developed during short-term maximal exercises.

The aim of this work was therefore to study the effect of chronic hypoxia and socioeconomic and nutritional status on the $\dot{V}O_{2\,max}$ and anaerobic power of Bolivian boys.

METHODS

The study was conducted in La Paz (altitude 3,600 m) and Santa Cruz de la Sierra (altitude 420 m), Bolivia.

Subjects

After explanation of the purposes of the study and what was expected of the children, written consent was obtained in each case. Age was recorded to the nearest month, and only boys 10–11 years old were recruited. The boys' exact ages were checked by using their official birth certificates.

At both HA and LA, children were grouped according to socioeconomic status. They were judged to belong to the lower or upper socioeconomic level by the dwelling location and kind and the type of school they attended (private or free public schools). Most of the children from a high socioeconomic background lived in the town center and attended a private school. The children from a low socioeconomic background lived in the poor suburbs (barrios) of the town where there were very poor levels of hygiene. They attended free public schools. Every boy underwent a thorough physical examination and was questioned about his medical history by a team pediatrician. The sexual maturation of the child was determined as described by Tanner. Pubertal boys or boys with pulmonary or cardiac disease, anemia, or obesity were excluded from the study.

Experimental Procedure

The study was conducted at HA at the Instituto Boliviano de Biología de Altura (altitude 3,600 m; pressure 498 Torr; ambient temperature 16.4 ± 1.0°C) and at LA at the Centro Nacional de Enfermades Tropicales (altitude 420 m; pressure 725 Torr; ambient temperature 20.7 ± 2.9°C). The methods and materials used were exactly the same at both altitudes.

Anthropometry. Height (H), body weight (BW), and upper arm circumference were determined for each boy by the same researcher. Skinfold thicknesses (biceps, triceps, subscapular, and suprailiac) were determined with a Harpenden skinfold caliper. The equation of Durnin and Rahaman (14) was used to determine the percentage of body fat mass. Lean body mass (LBM) was determined from BW and body fat mass. In addition, an index of body mass (BW/H^2) was calculated for each boy. Upper arm muscle circumference (UAMC) was calculated following the method of Jelliffe (30).

Hematologic parameters. A 5-ml blood sample was drawn from an antecubital vein. The hematocrit (microhematocrit method) and the hemoglobin concentration (Drabkin method) were determined from this sample.

Maximal exercise. The exercise bouts were conducted on a Brue cycle ergometer (8) of which the seat height, handlebars, and pedal crank were adjusted to child size. The cycle was calibrated according to the method described by Van Praagh et al. (49). $\dot{V}O_{2\,max}$ was determined by the direct method. The pedaling frequency was maintained at 70 rpm, and the heart rate (HR) was recorded on an electrocardiogram. The subjects performed 3–4 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 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 HA and LA. Analyzers were calibrated before and during each experimentation by use of standard gas mixtures. We included in the study only the data of boys from whom criteria of $\dot{V}O_{2\,max}$ were achieved [actual exhaustion, respiratory gas exchange ratio above unity, and maximal HR (HRmax) close to the maximum value that differed according to the altitude of residence].

Anaerobic tests. The exercise bouts were conducted on the same cycle ergometer as for the maximal exercise. The boys took part in a force-velocity test and a 30-s Wingate test.

FORCE-VELOCITY TEST. The test consisted of performing short maximal sprints against different increasing braking forces (40, 48). After a 3-min warm-up (HR reaching 140–150 beats/min), the boys performed two or three sprints against low braking forces as learning exercises. Then the children rested for 4 min before the test. The subjects had to remain seated on the saddle throughout the test. Their feet were strapped to the pedals to prevent them from slipping. They were vigorously encouraged to reach the maximal pedaling rate as soon as possible. The maximal peak velocity that was reached in 6–10 s, depending on the group, was recorded with a digital tachimeter. The test began with a braking force equal to 0.5 kg. After a 3-min recovery period in a recumbent position, the braking force was increased by 0.5 kg. The test was stopped when the power (product of the peak velocity and the braking force) was no longer seen to increase. The boys generally performed five or six sprints in the session. The force-velocity and force-power relationships were recorded on an Apple 2 computer. The braking force and the velocity for which the maximal anaerobic power (Pmax) was obtained corresponded to the optimal force (F_o) and the optimal velocity (V_o), respectively.

30-S WINGATE TEST. One hour later, the boys were studied again. The warm-up was the same as that of the force-velocity test. After a 4-min rest period, the boys had to pedal against the F_o determined during the previous test as fast as possible for 30 s. The subjects had to remain seated on the saddle throughout the test and were vigorously encouraged to reach maximal velocity. The mean P ($\bar{P}$) was calculated from the total number of pedal revolutions during 30 s and from the F_o applied.

Statistical Analysis

The mean data of each group were compared by using analysis of variance (Stat View SE plus graphics package). A standard paired t test was used to compare with in

TABLE 1. *Biometric characteristics of HA_1, HA_2, LA_1, and LA_2 boys*

	HA_1	HA_2	LA_1	LA_2	Statistical Analysis
n	23	44	48	30	
Height, cm	140±7	131±5	141±5	132±6	HA_1 vs. HA_2* LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Body weight, kg	37±9	30±4	36±5	31±4	HA_1 vs. HA_2* LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Body fat mass, %	21.3±5.8	16.5±3.3	21.3±4.5	17.8±3.6	HA_1 vs. HA_2* LA_1 vs. LA_2† HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Lean body mass, kg	29±5	25±2	28±3	25±3	HA_1 vs. HA_2* LA_1 vs. LA_2† HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Body mass index, kg/cm^2	18.6±2.9	17.2±1.7	17.9±1.8	17.6±2.2	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Upper arm muscle circumference, cm	19.5±2.2	17.4±1.2	18.7±1.3	17.8±1.3	HA_1 vs. HA_2* LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS

Values are means ± SD; *n*, no. of subjects. HA_1 and HA_2, highland boys from high and low socioeconomic backgrounds, respectively; LA_1 and LA_2, lowland boys from high and low socioeconomic backgrounds, respectively. * $P < 0.001$; † $P < 0.01$.

the same group both the mean data observed and the mean data calculated from predictive equations. Statistical significance was chosen as $P < 0.05$.

RESULTS

Anthropometry

The biometric characteristics of highland boys of high and low socioeconomic backgrounds (HA_1 and HA_2, respectively) and lowland boys of high and low socioeconomic backgrounds (LA_1 and LA_2, respectively) are presented in Table 1. For the overall anthropometric parameters, there was no significant difference between HA and LA boys of the same socioeconomic status. Regardless of altitude, boys from a high socioeconomic background were significantly taller ($P < 0.001$), heavier ($P < 0.001$), and fatter ($P < 0.001$) and had higher LBM and UAMC ($P < 0.001$) than boys from a low socioeconomic background. There was, however, no significant difference between boys from high and low socioeconomic backgrounds for the body mass index.

Hematologic Parameters

The hematologic parameters are presented in Table 2. The hematocrit and hemoglobin concentrations were significantly ($P < 0.001$) higher in HA than in LA boys. There was no significant difference between HA_1 and HA_2 boys for the hematocrit and hemoglobin concentrations and between LA_1 and LA_2 boys for the hemoglobin concentrations. The hematocrit of LA_1 boys was significantly higher ($P < 0.01$) than that of LA_2 boys.

Bioenergetic Characteristics

Maximal exercise. The bioenergetic characteristics determined from the maximal exercise are presented in Table 3. Regardless of altitude, $\dot{V}o_{2\,max}$ (l/min) of boys from a high socioeconomic background was significantly higher ($P < 0.05$) than that of boys from a low socioeconomic background. However, when expressed per kilogram of BW or LBM, no significant difference was observed between the two socioeconomic classes. HRmax of HA_1 and LA_1 boys were 6 beats/min (NS) and 7 beats/min ($P < 0.05$) faster than those of HA_2 and LA_2 boys, respectively. $\dot{V}o_{2\,max}$ (l/min) of HA_1 and HA_2 boys were 8.1 and 9.4% (NS) lower than that of their LA_1 and LA_2 counterparts, respectively. When expressed per kilogram of BW ($ml \cdot min^{-1} \cdot kg^{-1}$), the differences between HA and LA boys were 12.6% ($P < 0.05$) for the high socioeconomic class and 8.8% (NS) for the low socioeconomic class. When only LBM was taken into account ($ml \cdot min^{-1} \cdot kg^{-1}$), the differences between HA and LA boys from a similar socioeconomic background were all significant ($HA_1 - LA_1$: 11.7%, $P < 0.05$; $HA_2 - LA_2$: 10.1%, $P < 0.05$). HRmax of the HA_1 and HA_2 boys were 7 beats/min ($P < 0.05$) and 6 beats/min ($P < 0.05$) slower than that of their lowland counterparts.

Force-velocity test. At both HA and LA, V_o, F_o, and Pmax were significantly higher in boys of high socioeconomic level than in boys of low socioeconomic level (Ta-

TABLE 2. *Hematologic parameters of HA_1, HA_2, LA_1, and LA_2 boys*

	HA_1	HA_2	LA_1	LA_2	Statistical Analysis
n	19	43	39	18	
Hematocrit, %	45.9±2.8	45.7±2.1	42.4±2.3	39.9±2.1	HA_1 vs. HA_2, NS LA_1 vs. LA_2* HA_1 vs. LA_1† HA_2 vs. LA_2†
Hemoglobin, g/l	150±9	153±8	135±9	128±12	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1† HA_2 vs. LA_2†

Values are means ± SD; *n*, no. of subjects. * $P < 0.01$; † $P < 0.001$.

ble 4). However, there were no significant differences for V_o, F_o, and Pmax between HA and LA boys of the same socioeconomic class. Similar results were obtained for Pmax expressed in relative terms (HA_1: 6.8 ± 1.0, HA_2: 5.5 ± 0.8, LA_1: 7.1 ± 1.0, and LA_2: 5.3 ± 0.8 W/kg BW) (Fig. 1).

30-s Wingate test. Regardless of altitude, $\bar{P}$ of HA_1 and LA_1 boys was significantly higher ($P < 0.001$) than that of HA_2 and LA_2 boys. However, when the boys belonging to the same socioeconomic class were considered, there was no significant difference between the HA and LA boys in $\bar{P}$ (HA_1: 193 ± 53, HA_2: 133 ± 34, LA_1: 183 ± 29, and LA_2: 124 ± 22 W). When $\bar{P}$ was expressed in relative terms, the same conclusions were obtained (HA_1: 5.2 ± 0.8, HA_2: 4.5 ± 0.9, LA_1: 5.2 ± 0.7, and LA_2: 4.0 ± 0.6 W/kg BW) (Fig. 2).

DISCUSSION

Numerous studies have shown that, in children living in developing countries, poor socioeconomic and hygienic conditions result in a high incidence of undernutrition, which is largely marginal, particularly among the school-aged population. One of the most important char-

TABLE 3. *Bioenergetic characteristics of HA_1, HA_2, LA_1, and LA_2 boys*

	HA_1	HA_2	LA_1	LA_2	Statistical Analysis
n	23	44	25	40	
$\dot{V}O_{2\,max}$, l/min	1.36±0.28	1.15±0.23	1.48±0.18	1.25±0.14	HA_1 vs. HA_2† LA_1 vs. LA_2† HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
$\dot{V}O_{2\,max}$, $ml \cdot min^{-1} \cdot kg\ BW^{-1}$	37.2±5.6	38.9±6.4	42.5±5.8	42.5±5.3	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1* HA_2 vs. LA_2, NS
$\dot{V}O_{2\,max}$, $ml \cdot min^{-1} \cdot kg\ LBM^{-1}$	47.4±6.3	46.7±7.5	53.7±6.1	51.6±5.9	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1† HA_2 vs. LA_2*
HRmax, beats/min	190±5	184±12	197±7	190±10	HA_1 vs. HA_2, NS LA_1 vs. LA_2* HA_1 vs. LA_1* HA_2 vs. LA_2*
R	1.02±0.11	1.05±0.11	1.12±0.06	1.10±0.07	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1† HA_2 vs. LA_2, NS
$\dot{V}E$ BTPS, l/min	73.5±10	68±13	65.5±11	58±7	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1, NS HA_2 vs. LA_2*
$\dot{V}E$ BTPS/$\dot{V}O_2$ STPD	54.5±5.2	59.8±10.4	44.3±5.6	46.5±4.6	HA_1 vs. HA_2, NS LA_1 vs. LA_2, NS HA_1 vs. LA_1‡ HA_2 vs. LA_2‡

Values are means ± SD obtained from maximal exercise; *n*, no. of subjects. $\dot{V}O_{2\,max}$, maximal O_2 uptake; BW, body weight; LBM, lean body mass; HRmax, maximal heart rate; R, respiratory exchange ratio; $\dot{V}E$, minute ventilation. * $P < 0.05$; † $P < 0.01$; ‡ $P < 0.001$.

TABLE 4. *V_o, F_o, and Pmax of boys during the force-velocity test*

	HA_1	HA_2	LA_1	LA_2	Statistical Analysis
n	23	44	48	30	
V_o, rpm	103±8	90±9	108±8	94±11	HA_1 vs. HA_2* LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
F_o, g/kg BW	67±10	61±9	66±9	57±9	HA_1 vs. HA_2† LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS
Pmax, W	251±69	164±35	250±41	163±34	HA_1 vs. HA_2* LA_1 vs. LA_2* HA_1 vs. LA_1, NS HA_2 vs. LA_2, NS

Values are means ± SD; *n*, no. of subjects. V_o, optimal velocity; F_o, optimal force; Pmax, maximal anaerobic power. * $P < 0.001$; † $P < 0.05$.

acteristics of marginal malnutrition is a delay in the physical growth of children (1, 33, 45). In the present study, HA_2 and LA_2 boys living in poor socioeconomic and hygienic conditions were two years behind their HA_1 and LA_1 well-to-do counterparts of the same age. This is an indication of physical growth retardation due to nutritional deprivation. Several classifications have been proposed in the literature to classify the nutritional status of children (22, 30). These classifications are based on the concepts of BW and H expressed as percentages of those expected for a given age. American norms are used as reference data for well-nourished children. Various degrees of malnutrition (mild, moderate, and severe) are determined according to the deficit recorded against the American norms. Such classifications applied to our groups show that HA_1 and LA_1 boys can be considered well nourished and that HA_2 and LA_2 boys have first-degree malnutrition (mild malnutrition). The marginal nutritional status of HA_2 and LA_2 boys can also be demonstrated by measurement of UAMC and body fat mass. These criteria, which reflect the protein and calorie reserves of the children, are in fact significantly lower in HA_2 and LA_2 boys than in HA_1 and LA_1 boys. In addition, biochemical analyses were performed from a venous sample to determine serum total protein, albumin, and prealbumin concentrations. The results indicated marginal nutrition in boys from low socioeconomic backgrounds. Finally, dietary information showed that mean energy and nutrient (protein, fat, and carbohydrate) intakes were marginal in boys from low socioeconomic backgrounds (36). No difference was observed between the biometric characteristics of HA and LA boys of the same socioeconomic status. This is in agreement with the results of other studies (24, 26) showing that, when other factors such as health, socioeconomic, and nutritional status are taken into account, altitude (<3,800 m) has no effect on the physical growth of children.

The first important feature of this study is that a marginal state of malnutrition did not alter the $\dot{V}O_{2\,max}$ of prepubertal boys living at HA or LA, nor was a significant difference in $\dot{V}O_{2\,max}$ observed between HA_1 and HA_2 boys (37.2 ± 5.6 vs. 38.9 ± 6.4 ml · min^{-1} · kg^{-1} BW). Until now, there was no report on $\dot{V}O_{2\,max}$ of marginally undernourished boys living at HA. Greksa et al. (27) studied in La Paz 11- to 12-yr-old Aymara boys from a low socioeconomic background, but these boys were considered healthy and well nourished. $\dot{V}O_{2\,max}$ of the well-nourished

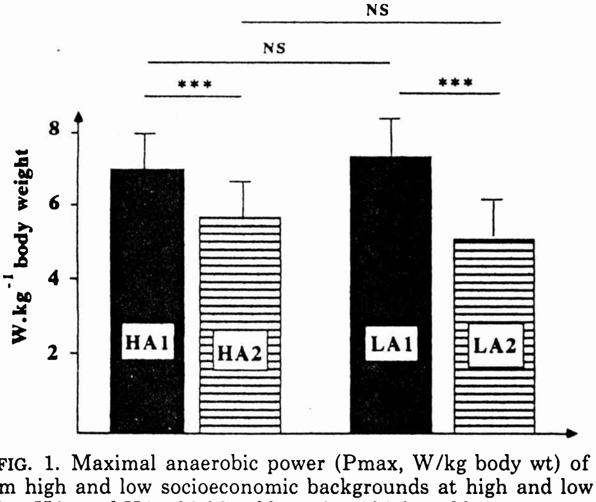

FIG. 1. Maximal anaerobic power (Pmax, W/kg body wt) of boys from high and low socioeconomic backgrounds at high and low altitudes. HA_1 and HA_2, highland boys from high and low socioeconomic backgrounds, respectively; LA_1 and LA_2, lowland boys from high and low socioeconomic backgrounds, respectively. ***$P < 0.001$. NS, not significant.

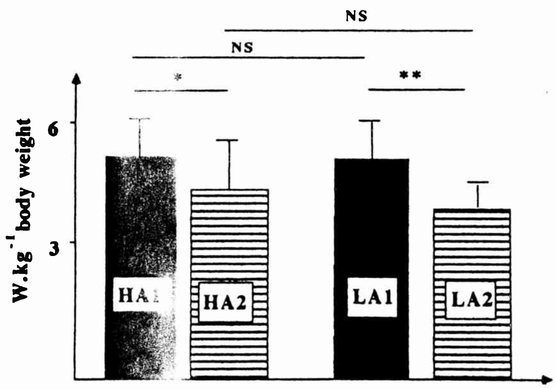

FIG. 2. Mean anaerobic power ($\bar{P}$, W/kg body wt) of HA_1, HA_2, LA_1, and LA_2 boys. *$P < 0.05$; **$P < 0.01$. NS, not significant.

boys (HA_1) was slightly lower than that of well-to-do boys studied previously in La Paz (18, 19, 24). The discrepancy might be due to different levels of physical activity and methodology (treadmill vs. cycle ergometer). Moreover, in all cases, HA_1 and HA_2 boys had lower $\dot{V}O_{2\,max}$ (on average, 10% less) compared with their LA_1 and LA_2 counterparts. Similar results were obtained previously by our team using untrained well-nourished boys (7, 18, 19) and by Greksa et al. (25) using adolescent swimmers trained in La Paz and selected athletes trained at sea level. As at HA, no significant difference was observed at LA in $\dot{V}O_{2\,max}$ of boys from high and low socioeconomic backgrounds (LA_1: 42.5 ± 5.8; LA_2: 42.5 ± 5.3 $ml \cdot min^{-1} \cdot kg^{-1}$ BW). Our results are in line with those observed in marginally undernourished Colombian boys (5, 44, 46) and in young Guatemalan adults of low socioeconomic status (50). However, $\dot{V}O_{2\,max}$ of LA_1 and LA_2 boys were lower than those obtained by Spurr et al. (44, 46) using either a treadmill or a cycle ergometer (51–55 vs. 43 $ml \cdot min^{-1} \cdot kg^{-1}$ BW). This may be due to the very poor level of physical fitness of the LA_1 and LA_2 boys. Santa Cruz de la Sierra is located in a tropical zone and has a very hot and humid climate for 9 mo of the year. These ambient conditions and also sociocultural factors may lead to reduced voluntary physical activity among these children, which could explain their very poor physical fitness. As a result, the differences between HA_1 and HA_2 and LA_1 and LA_2 boys could perhaps have been minimized, and the differences >9–10% would have been found. Moreover, this could well explain the absence of any significant differences between HA and LA boys for $\dot{V}O_{2\,max}$ expressed in liters per minute.

At both altitudes, $\dot{V}O_{2\,max}$ (in l/min) of well-nourished boys was significantly higher ($P < 0.05$) than that of marginally undernourished boys. However, the difference was eliminated when $\dot{V}O_{2\,max}$ was expressed per kilogram of BW or LBM. Similarly, at LA, Areskog et al. (3) in 10- to 13-yr-old Ethiopian boys and Satyanarayana et al. (41) in 14- to 17-yr-old Indian adolescents have shown that the physical work capacity (PWC_{170}) (31) of the well-nourished subjects, corrected for BW or LBM, was not different from that of the marginally undernourished subjects. Thus, it appears that the reduction in the $\dot{V}O_{2\,max}$ or PWC_{170} of a marginally undernourished boy is due to a reduction in BW, principally in muscle mass. This decrease in muscle mass appears to be due principally to a reduction in the diameter of type II fibers, that of type I fibers being far less decreased (16, 28, 39).

The second salient feature of this study is that HA boys developed the same Pmax and $\bar{P}$ as their LA counterparts of the same socioeconomic class. To our knowledge, only our team reported the effect of altitude on P developed by children during short exercises. Bedu et al. (7) studied 7- to 15-yr-old boys from a high socioeconomic background. They found, using the same methodology as described in this study, that boys living at 3,600 m (La Paz, Bolivia) developed the same Pmax during the force-velocity test as boys living at LA (Clermont-Ferrand, France). This finding is in accordance with the results of this study for boys from both high and low socioeconomic backgrounds. Bedu et al. showed, however, that $\bar{P}$ sustained during the 30-s Wingate test was significantly lower at HA for 11- to 15-yr-old boys. The difference between HA and LA boys appeared with the onset of puberty and increased with puberty. In the present study, all the boys were classified as prepubertal according to Tanner's tables (Tanner stage: 1). Thus, the difference between the two studies may be explained by the fact that in the 11- to 12-yr-old group of Bedu et al., puberty had already started for certain boys. To our knowledge, there is no report on the effect of altitude on the anaerobic metabolism of boys belonging to a low socioeconomic class. To conclude, it appears that an altitude of 3,600 m has no effect on anaerobic performances during a force-velocity test and a Wingate test in prepubertal boys. This is true for boys of both high and low socioeconomic status.

The third point of interest of this study is that, at both HA and LA, Pmax and $\bar{P}$ developed by HA_1 and LA_1 boys were significantly higher than those developed by HA_2 and LA_2 boys. The difference persisted when Pmax and $\bar{P}$ were expressed per kilogram of BW (Figs. 1 and 2). Several studies (12, 13) have shown that P was strongly related to certain biometric characteristics, such as BW, H, and LBM. As seen previously, regardless of altitude, considerable differences existed between the body dimensions of boys from high and low socioeconomic backgrounds. Thus, one would expect that the differences observed between HA_1 and HA_2 and between LA_1 and LA_2 boys are the result of difference in body dimensions. Predictive equations of Pmax and $\bar{P}$ from biometric parameters and age have been established by Bedu (unpublished data) from an analysis of 148 boys from a high socioeconomic background living at HA (3,600 m, La Paz, Bolivia) and LA (320 m, Clermont-Ferrand, France). Such equations applied to HA_2 and LA_2 groups of this study are presented in Table 5. It appears that HA_2 and LA_2 boys developed significantly lower ($P < 0.001$) Pmax and $\bar{P}$ than boys of the same BW and H but of a high socioeconomic level and nutritionally normal. Pmax and $\bar{P}$ of HA_1 and LA_1 children are close to those values obtained by Bedu's team for boys of the same age (10–11 yr) of high socioeconomic status living at HA (3,600 m, La Paz, Bolivia) (7) and LA (320 m, Clermont-Ferrand, France) (17). As a results, factors other than body dimensions may account for the differences in Pmax and $\bar{P}$ of boys of high and low socioeconomic status.

We showed that HA_2 and LA_2 boys can be considered marginally undernourished. Therefore, are lower Pmax and $\bar{P}$ observed in HA_2 and LA_2 boys a direct consequence of impaired muscle function due to nutritional deprivation during infancy and childhood? Several studies have concentrated on the metabolic, structural, and functional changes occurring in human skeletal muscle as a result of malnutrition or nutritional restriction. Muscle function tests have been performed to study the effect of severe malnutrition (32, 43), hypocaloric dieting and fasting (37, 39), and anorexia nervosa (38) on muscle function. The forces generated by the adductor pollicis muscle in response to different electrical stimulations of the ulnar nerve were recorded (15). These studies showed that nutritional stress results in both increased muscle fatigability and an altered pattern of muscle contraction and relaxation. Moreover, the functional changes ob-

TABLE 5. *Pmax and $\bar{P}$ observed and calculated from equation of Bedu (unpublished data) in HA_2 and LA_2 boys*

	Predictive Equations of Bedu	Observed Values	Predicted Values
HA_2	Pmax = 13.45 kg BW − 185	164±35	214±57
	$\bar{P}$ = 8.67 kg BW − 106	133±34	151±36
LA_2	Pmax = 8.34 kg BW + 4.72 cm H − 668	163±34	208±52
	$\bar{P}$ = 5.62 kg BW + 7.6 yr-A + 2.15 cm H − 366	124±22	170±32

Values are means ± SD. $\bar{P}$, mean anaerobic power; H, height; A, age. All observed values differed significantly from predicted values ($P < 0.001$).

served could be rapidly reversed by refeeding and were evident when significant changes in body composition could not be detected. Similar results were found by Jeejeebhoy (29) in rats after hypocaloric dieting and fasting. These observations led the authors to conclude that this technique of muscle function testing was more sensitive than standard methods of nutritional assessment in detecting subtle changes in body function during nutritional stress conditions. In addition to muscle function tests, muscle biopsies were performed to assess the effect of malnutrition on skeletal muscle. These showed that malnutrition results in muscular atrophy due to a decrease in the area of the fibers and that a high-energy feeding regimen permits the subjects to rapidly recover to almost the same muscle mass as a normal subject of the same BW and H by means of a combination of cellular hypertrophy and hyperplasia (11, 28). Furthermore, Goldspink (21) 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. (42) showed that, in normal subjects, a 2-wk hypocaloric diet resulted in a reduction in the size of the fast-twitch fibers of the triceps brachii and quadriceps femoris muscles but that the size of the slow-twitch fibers was not affected. In line with these results are the findings of Russell et al. (39) in fasting patients and of Essén et al. (16) in patients with anorexia nervosa. They found that the size of the slow-twitch fibers in the human calf and thigh muscles were better preserved than that of the fast twitch fibers. Russell et al. even reported a fast-to-slow fiber transformation in obese subjects after hypocaloric dieting and fasting, but there is no evidence that this occurs as a consequence of long-term energy deficiency. Finally, studies in fasting patients (39) and patients with anorexia (16) have shown a decrease in the activity of the enzymes responsible for both anaerobic glycolysis (phosphofructokinase) and oxidative metabolism (succinate dehydrogenase) but no modification of the activity of the enzyme responsible for fat oxidation (acyl-CoA dehydrogenase).

To conclude this point, there is evidence that, in children as in adults, nutritional deprivation (hypocaloric dieting and fasting, anorexia nervosa, or severe malnutrition) results in metabolic and structural changes of skeletal muscle. According to Russell et al. (39) and Jeejeebhoy (29), such modifications might explain the changes observed in the muscle function of malnourished and fasting patients (altered force-frequency curve, slower maximal relaxation rate, and higher muscle fatigability). Consequently, one would expect that in malnourished patients, high contraction speed movements, involving principally fast twitch fibers and using for the most part energy from glycolysis, might be limited. Because of ethical limitations, we did not carry out muscular biopsies and we did not know whether such metabolic and structural changes occurred in the skeletal muscle of our marginally undernourished HA_2 and LA_2 children. Gregor et al. (23) and Thorstensson et al. (47) have demonstrated a significant relationship between both the percentage and the relative area of type II fibers in a contractile muscle and the peak power and the maximal knee extension velocity determined under isokinetic loading conditions. Furthermore, McCartney et al. (35) have shown that during short-term maximal exercises on a constant-velocity cycle ergometer that a high proportion of type II fibers may be one of the factors associated with a high crank velocity for Pmax. As seen previously, Pmax of HA_2 and LA_2 boys were significantly lower than those of HA_1 and LA_1 boys (see Fig. 1). Moreover, V_o was significantly lower in HA_2 and LA_2 boys than in HA_1 and LA_1 boys (Table 4). These observations might indicate a lower proportion of type II fibers in HA_2 and LA_2 children. We also noticed during the experiments that many boys could not pedal properly, particularly at high velocity. Many of them had never cycled and had problems of coordination. This was, however, true for both the well-nourished and the marginally undernourished boys.

In conclusion, it appears that a marginal malnutrition results in lower $\dot{V}O_{2\,max}$ (l/min), which is due primarily to a reduction in body composition (principally muscle mass). This phenomenon was observed at both LA and HA. Altitude has no influence on Pmax and $\bar{P}$ of prepubertal boys of the same socioeconomic class. However, regardless of altitude, poor socioeconomic and nutritional conditions lead to lower power developed during short-term maximal exercises. This cannot be fully explained by reduction in body size. Others factors, such as a decrease in the proportion of muscle type II fibers because of nutritional stress and a reduced ability to perform on a bicycle because of coordination problems, are also some possible explanations for this phenomenon. However, this phenomenon needs further investigation.

The authors thank Esperanza Caceres and Vilma Tellez, Instituto Boliviano de Biología de Altura, and Rolando Urgel, Centro Nacional de Enfermades Tropicales, for their expert assistance. We thank Enrique Vargas, director of the Instituto Boliviano de Biología de Altura, and Benjamin Ribera, director of the Centro Nacional de Enfermades Tropicales, for allowing us to work in their laboratories. We also express our gratitude to the headmasters of the following schools: Colegio Franco Boliviano, Colegio La Salle, Colegio Hernando Siles (Villa Fatima), and Colegio Amboro.

This work has been supported by the European Community (Contract number: CI 1 */0507-F).

Address for reprint requests: J. Coudert, Laboratoire de Physiologie, Faculté de Médecine, place H. Dunant, BP 38-63001, Clermont-Ferrand, France.

Received 9 April 1992; accepted in final form 28 August 1992.

REFERENCES

1. Adrianzen, B. T., J. M. Baert, and G. G. Graham. Growth of children from extremely poor families. *Am. J. Clin. Nutr.* 26: 926–930, 1973.
2. Andersen, K. L. The effect of altitude variation on the physical performance capacity of Ethiopian men. II. Development of physical performance during adolescence. In: *Physical Fitness,* edited by V. Seliger. Prague, Czechoslovakia: Charles University, 1973, p. 34–36.
3. Areskog, N. H., R. Selinus, and B. Vahlquist. Physical work capacity and nutritional status in Ethiopian male children and young adults. *Am. J. Clin. Nutr.* 22: 471–479, 1969.
4. Baker, P. T. Work performances of highland natives. In: *Man in the Andes: A Multidisciplinary Study of High Altitude Quechua Natives,* edited by P. T. Baker and M. A. Little. Stroudsburg, PA: Dowden, Hutchinson & Ross, 1976, p. 301–314.
5. Barac-Nieto, M., G. B. Spurr, M. G. Maksud, and H. Lotero. Aerobic capacity in chronically undernourished adult males. *J. Appl. Physiol.* 44: 209–215, 1978.
6. Barac-Nieto, M., G. B. Spurr, and J. C. Reina. Marginal malnutrition in school-aged Colombian boys: body composition and maximal O_2 consumption. *Am. J. Clin. Nutr.* 39: 830–839, 1984.
7. Bedu, M., N. Fellmann, H. Spielvogel, G. Falgairette, E. Van Praagh, and J. Coudert. Force-velocity and 30-s Wingate tests in boys at high and low altitudes. *J. Appl. Physiol.* 70: 1031–1037, 1991.
8. Brue, F., and B. Melin. The direct determination of maximal aerobic and anaerobic power using a new mechanical cycle ergometer. *Proc. North Atlantic Treaty Organization Meet. RSG 45th Brussels 11–15 Sept. 1983.*
9. Buskirk, E. R. Work performance of newcomers to the Peruvian highlands. In: *Man in the Andes: A Multidisciplinary Study of High Altitude Quechua Natives,* edited by P. T. Baker and M. A. Little. Stroudsburg, PA: Dowden, Hutchinson & Ross, 1976, p. 283–299.
10. Buskirk, E. R. Work capacity of high altitude natives. In: *The Biology of High Altitude Peoples,* edited by P. T. Baker. Cambridge, UK: Cambridge Univ. Press, 1978, p. 173–187.
11. Cheek, D. B., E. H. Donald, A. Cordano, and G. G. Graham. Malnutrition in infancy: changes in muscle and adipose tissue before and after rehabilitation. *Pediatr. Res.* 4: 135–144, 1970.
12. Cumming, G. R. Correlation of athletic performance and aerobic power in 12 to 17 year old children with bone age, calf muscle, total body potassium, heart volume and two indices of anaerobic power. In: *Proceedings of the 4th International Symposium on Pediatric Work Physiology,* edited by O. Bar-Or. Israel: Natanya Wingate Institute, 1979, p. 109–134.
13. Davies, C. T. M., C. Barnes, and S. Godfrey. Body composition and maximal exercise performance in children. *Hum. Biol.* 44: 195–214, 1972.
14. Durnin, J. V. G. A., and M. M. Rahaman. The assessment of the amount of fat in the human body from measurements of skinfold thicknesses. *Br. J. Nutr.* 21: 681–689, 1967.
15. Edwards, R. H. T., A. Young, G. P. Hosking, and D. A. Jones. Human skeletal muscle function: description of tests and normal values. *Clin. Sci. Mol. Med.* 52: 283–290, 1977.
16. Essén, B., L. Folhin, C. Thorén, and B. Saltin. Skeletal muscle fibre types and sizes in anorexia nervosa patients. *Clin. Physiol. Oxf.* 1: 395–403, 1981.
17. Falgairette, G., M. Bedu, N. Fellmann, E. Van Praagh, and J. Coudert. Bio-energetic profile in 144 boys aged from 6 to 15 years with special reference to sexual maturation. *Eur. J. Appl. Physiol. Occup. Physiol.* 62: 151–156, 1991.
18. Fellmann, N., M. Bedu, H. Spielvogel, G. Falgairette, E. Van Praagh, and J. Coudert. Oxygen debt in submaximal and supramaximal exercises in children at high and low altitude. *J. Appl. Physiol.* 60: 209–215, 1986.
19. Fellmann, N., M. Bedu, H. Spielvogel, G. Falgairette, E. Van Praagh, J. F. Jarrige, and J. Coudert. Anaerobic metabolism during pubertal development at high altitude. *J. Appl. Physiol.* 64: 1382–1386, 1988.
20. Frisancho, A. R., C. Martinez, T. Velasquez, J. Sanchez, and H. Montoye. Influence of developmental adaptation on aerobic capacity at high altitude. *J. Appl. Physiol.* 34: 176–180, 1973.
21. Goldspink, D. F. The influence of contractile activity and the nerve supply on muscle size and protein turnover. In: *Plasticity of Muscle,* edited by D. Pette. Berlin: de Gruyter, 1980, p. 525–539.
22. Gomez, F., R. R. Galvan, S. Frenk, J. C. Munoz, R. Chavez, and J. Vasquez. Mortality in second and third degree malnutrition. *J. Trop. Pediatr.* 2: 77–83, 1956.
23. Gregor, R. J., V. R. Edgerton, J. J. Perrine, D. S. Campion, and C. Debus. Torque-velocity relationships and muscle fiber composition in elite female athletes. *J. Appl. Physiol.* 47: 388–392, 1979.
24. Greksa, L. P., and J. D. Haas. Physical growth and maximal work capacity in preadolescent boys at high altitude. *Hum. Biol.* 54: 677–695, 1982.
25. Greksa, L. P., J. D. Haas, T. L. Leatherman, R. B. Thomas, H. Spielvogel, and M. Paz Zamora. Maximal aerobic power in trained youths at high altitude. *Ann. Hum. Biol.* 9: 201–209, 1982.
26. Greksa, L. P., H. Spielvogel, and E. Caceres. Effect of altitude on the physical growth of upper-class children of European ancestry. *Ann. Hum. Biol.* 12: 225–232, 1985.
27. Greksa, L. P., H. Spielvogel, and L. Paredes-Fernandez. Maximal exercise capacity in adolescent European and Amerindian high-altitude natives. *Am. J. Phys. Anthropol.* 67: 209–216, 1985.
28. Henriksson, J. The possible role of skeletal muscle in the adaptation to periods of energy deficiency. *Eur. J. Clin. Nutr.* 44, *Suppl.* 1: 55–64, 1990.
29. Jeejeebhoy, K. N. Muscle function and nutrition. *Gut* 27, *Suppl.* 1: 25–39, 1986.
30. Jelliffe, D. B. *The Assessement of the Nutritional Status of the Community.* Geneva: World Health Organization, 1966, p. 245. (Monograph 53)
31. Johnson, R. E., L. Brouha, and R. C. Darling. A test of physical fitness for strenuous exertion. *Rev. Can. Biol.* 1: 491–503, 1942.
32. Lopes, J., D. M. Russell, J. Whitwell, and K. N. Jeejeebhoy. Skeletal muscle function in malnutrition. *Am. J. Clin. Nutr.* 36: 602–610, 1982.
33. Martorell, R. Child growth retardation: a discussion for its causes and its relationship to health. In: *Nutritional Adaptation in Man,* edited by K. Blaxter and J. C. Waterlow. London: Libbey, 1985, p. 13–30.
34. Mazess, R. B. Exercise performance at high altitude (4000 m) in Peru. *Federation Proc.* 28: 1301–1306, 1969.
35. McCartney, N., G. J. F. Heigenhauser, and N. L. Jones. Power output and fatigue of human muscle in maximal cycling exercise. *J. Appl. Physiol.* 55: 218–224, 1983.
36. Post, G. B., H. C. G. Kemper, C. Lujan, G. Parent, and J. Coudert. Comparison of 10–12 years old schoolboys living at high (4100 m) and low (450 m) altitude in Bolivia. *Int. J. Sports Med.* 13: 88, 1992.
37. Russell, D. M., L. A. Leiter, J. Whitwell, E. B. Marliss, and K. N. Jeejeebhoy. Skeletal muscle function during hypocaloric diets and fasting: a comparison with standard nutritional assessment parameters. *Am. J. Clin. Nutr.* 37: 133–138, 1983.
38. Russell, D. M., P. J. Prendergast, P. L. Darby, P. E. Garfinkel, J. Whitwell, and K. N. Jeejeebhoy. A comparison between muscle function and body composition in anorexia nervosa: the effect of refeeding. *Am. J. Clin. Nutr.* 38: 229–237, 1983.
39. Russell, D. M., P. M. Walker, L. A. Leiter, A. Sima, W. K. Tanner, D. A. G. Mickle, J. Whitwell, E. B. Marliss, and K. N. Jeejeebhoy. Metabolic and structural changes in skeletal muscle during hypocaloric dieting. *Am. J. Clin. Nutr.* 39: 503–513, 1984.
40. Sargeant, A., E. Hoinville, and A. Young. Maximum leg force and power output during short-term dynamic exercises. *J. Appl. Physiol.* 42: 514–518, 1977.
41. Satyanarayana, K., A. N. Naidu, and B. S. N. Rao. Nutritional deprivation in childhood and the body size, activity and physical

work capacity of young boys. *Am. J. Clin. Nutr.* 32: 1769–1775, 1979.
42. SCHANTZ, P., J. HENRIKSSON, AND E. JANSSON. Adaptation of human skeletal muscle to endurance training of long duration. *Clin. Physiol. Oxf.* 3: 141–151, 1983.
43. SHIZGAL, H. M., C. A. VASILEVSKY, P. F. GARDINER, W. WANG, D. A. QUELETTE TUIT, AND G. V. BRABANT. Nutritional assessment and skeletal muscle function. *Am. J. Clin. Nutr.* 44: 761–771, 1986.
44. SPURR, G. B., AND J. C. REINA. Maximum oxygen consumption in marginally malnourished Colombian boys and girls 6–16 years of age. *Am. J. Hum. Biol.* 1: 11–19, 1989.
45. SPURR, G. B., J. C. REINA, AND M. BARAC-NIETO. Marginal malnutrition in school-aged Colombian boys: anthropometry and maturation. *Am. J. Clin. Nutr.* 37: 119–132, 1983.
46. SPURR, G. B., J. C. REINA, H. W. DAHNERS, AND M. BARAC-NIETO. Marginal malnutrition in school-aged Colombian boys: functional consequences in maximum exercise. *Am. J. Clin. Nutr.* 37: 834–847, 1983.
47. THORSTENSSON, A., G. GRIMBY, AND J. KARLSSON. Force-velocity relations and fiber composition in human knee extensor muscles. *J. Appl. Physiol.* 40: 12–16, 1976.
48. VANDEWALLE, H., G. PERES, AND H. MONOD. Standard anaerobic exercise tests. *Sports Med.* 4: 268–289, 1987.
49. VAN PRAAGH, E., M. BEDU, P. RODDIER, AND J. COUDERT. A simple calibration method for mechanically braked cycle ergometers. *Int. J. Sports Med.* 13: 27–30, 1991.
50. VITERI, F. E. Considerations of the effect of nutrition on the body composition and physical work capacity of young Guatemalan adults. In: *Amino Acid Fortification of Protein Foods*, edited by N. S. Scrimshaw and A. M. Altschul. Cambridge, MA: MIT Press, 1971, p. 350–375.