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, AIDA 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, Aida 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 (HA1, n = 23, LA1, n = 48) and low (HA2, n = 44, LA2, n = 30) socioeconomic levels. Anthropometric characteristics, $V_{O_2 max}$, and P [ maximal P (Pmax)] during a force-velocity test and mean P (P̄) during a 30-s Wingate test were measured. Results showed that 1) anthropometric parameters were not different between HA and LA, and HA and LA boys, but HA and LA boys were two years behind HA and LA boys in development; 2) $V_{O_2 max}$ was not different in boys from the same altitude, but at HA $V_{O_2 max}$ was 10% lower than at LA (HA = 37.2 ± 5.6, HA = 38.9 ± 6.4, LA = 42.5 ± 5.8, LA = 42.5 ± 5.3 ml·min⁻¹·kg⁻¹ body wt); and 3) Pmax and P were higher in well-nourished than in undernourished boys, but there was no difference in Pmax and P between HA and LA, and HA and LA boys (HA = 6.8 ± 1.0, HA = 5.5 ± 0.8, LA = 7.1 ± 1.0, LA = 5.3 ± 0.9 W/kg for Pmax; HA = 5.2 ± 0.8, HA = 4.5 ± 0.9, LA = 5.2 ± 0.7, LA = 4.0 ± 0.6 W/kg for P). A marginal state of malnutrition had no effect on $V_{O_2 max}$ 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 ($V_{O_2 max}$) 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 $V_{O_2 max}$ 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 $V_{O_2 max}$ 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, $V_{O_2 max}$ 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.
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 Enfermedades 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, subcapular, 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/H²) 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). VO₂ 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 O₂ and CO₂ 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 VO₂ 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 tachometer. 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 (Fopt) and the optimal velocity (Vopt), 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 Fopt 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 (P) was calculated from the total number of pedal revolutions during 30 s and from the Fopt 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
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, \( V_{O2 \text{max}} \) \((l/min)\) 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. HR\(_{\text{max}}\) 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. \( V_{O2 \text{max}} \) \((l/min)\) 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 \((\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1})\), 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 \((\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1})\), the differences between HA and LA boys from a similar socioeconomic background were all significant \((HA_1 - LA_1: 11.7\%, P < 0.05; HA_2 - LA_2: 10.1\%, P < 0.05)\). HR\(_{\text{max}}\) 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 \( P_{\text{max}} \) were significantly higher in boys of high socioeconomic level than in boys of low socioeconomic level (Ta-
TABLE 2. Hematologic parameters of HA1, HA2, LA1, and LA2 boys

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Hematocrit, % 45.9±2.8 45.7±2.1 42.4±2.3 39.9±2.1

Hemoglobin, g/l 150±9 153±8 135±9 128±12

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

TABLE 3. Bioenergetic characteristics of HA1, HA2, LA1, and LA2 boys

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\( \dot{V}O_2 \) max, l/min 1.36±0.28 1.15±0.23 1.48±0.18 1.25±0.14

\( \dot{V}O_2 \) max, ml·min\(^{-1}\)·kg BW\(^{-1}\) 37.2±5.6 38.9±6.4 42.5±5.8 42.5±5.3

\( \dot{V}O_2 \) max, ml·min\(^{-1}\)·kg LBM\(^{-1}\) 47.4±6.3 46.7±7.5 53.7±6.1 51.6±5.9

HRmax, beats/min 190±5 184±12 197±7 190±10

R 1.02±0.11 1.05±0.11 1.12±0.06 1.10±0.07

\( \dot{V}E \) BTSF, l/min 73.5±10 68±13 65.5±11 58±7

\( \dot{V}E \) BTSF/\( \dot{V}O_2 \) STPD 54.5±5.2 59.8±10.4 44.3±5.6 46.5±4.6

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.
characteristics of marginal malnutrition is a delay in the physical growth of children (1, 33, 45). In the present study, HA₂ and LA₂ boys living in poor socioeconomic and hygienic conditions were two years behind their HA₁ and LA₁ 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 HA₁ and LA₁ boys can be considered well nourished and that HA₂ and LA₂ boys have first-degree malnutrition (mild malnutrition). The marginal nutritional status of HA₂ and LA₂ 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 HA₂ and LA₂ boys than in HA₁ and LA₁ 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 VO₂ max of prepubertal boys living at HA or LA, nor was a significant difference in VO₂ max observed between HA₁ and HA₂ boys (37.2 ± 5.6 vs. 38.9 ± 6.4 ml · min⁻¹ · kg⁻¹ BW). Until now, there was no report on VO₂ max of marginally undernourished boys living at HA. Greksa et al. (27) studied in La Paz 11- to 12-year-old Aymara boys from a low socioeconomic background, but these boys were considered healthy and well nourished. VO₂ max of the well-nourished

**TABLE 4. Vₒ, Fₒ, and Pmax of boys during the force-velocity test**

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<td>Vₒ, rpm</td>
<td>103±8</td>
<td>90±9</td>
<td>108±8</td>
<td>94±11</td>
<td>HA₁ vs. HA₂*</td>
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<td>Fₒ, g/kg BW</td>
<td>67±10</td>
<td>61±9</td>
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<td>57±9</td>
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<td>Pmax, W</td>
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Values are means ± SD; n, no. of subjects. Vₒ, optimal velocity; Fₒ, optimal force; Pmax, maximal anaerobic power. * P < 0.001; † P < 0.05.

![FIG. 1. Maximal anaerobic power (Pmax, W/kg body wt) of boys from high and low socioeconomic backgrounds at high and low altitudes. HA₁ and HA₂, highland boys from high and low socioeconomic backgrounds, respectively; LA₁ and LA₂, lowland boys from high and low socioeconomic backgrounds, respectively. ***P < 0.001. NS, not significant.](image1)

![FIG. 2. Mean anaerobic power (P, W/kg body wt) of HA₁, HA₂, LA₁, and LA₂ boys. * P < 0.05; ** P < 0.01. NS, not significant.](image2)
boys (HA_2) 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 \( V_{O_{2max}} \) (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 Grek 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 \( V_{O_{2max}} \) of boys from high and low socioeconomic backgrounds (LA_1: 42.5 ± 5.8; LA_2: 42.5 ± 5.3 ml·min^{-1}·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, \( V_{O_{2max}} \) 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·min^{-1}·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 boys persisted when \( V_{O_{2max}} \) was expressed per kilogram of BW or LBM. Similarly, at LA_1, 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 \( V_{O_{2max}} \) 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_2 boys developed the same \( P_{max} \) and \( P \) 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 \( P_{max} \) 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 \( P \) 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, \( P_{max} \) and \( P \) 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 \( P_{max} \) and \( P \) 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 \( P_{max} \) and \( P \) 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 (\( P < 0.001 \)) \( P_{max} \) and \( P \) than boys of the same BW and H but of a high socioeconomic level and nutritionally normal. \( P_{max} \) and \( P \) 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 result, factors other than body dimensions may account for the differences in \( P_{max} \) and \( P \) 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 \( P_{max} \) and \( P \) observed in HA_2 and LA_2 boys a direct consequence of impaired muscle function due to nutritional deprivation during infancy and childhood? 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, 49), 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-
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 Jee-
jeelhooy (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 detec-
ting subtle changes in body function during nutri-
tional 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 cellu-
lar 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 propor-
tion 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 tri-
ceps 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. Rus-
sell et al. even reported a fast-to-slow fiber transforma-
tion in obese subjects after hypocaloric dieting and fast-
ting, but there is no evidence that this occurs as a con-
sequence 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 respon-
sible 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 chil-
dren as in adults, nutritional deprivation (hypocaloric
dieting and fasting, anorexia nervosa, or severe malnu-
trition) results in metabolic and structural changes of
skeletal muscle. According to Russell et al. (39) and Jee-
jeelhooy (29), such modifications might explain the
changes observed in the muscle function of malnour-
ished and fasting patients (altered force-frequency
curve, slower maximal relaxation rate, and higher muscle
fatiguability). Consequently, one would expect that in
malnourished patients, high contraction speed move-
ments, involving principally fast twitch fibers and using
for the most part energy from glycolysis, might be lim-
ited. 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 HA2 and LA2
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 maxi-
mal 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 propor-
tion of type II fibers may be one of the factors associated
with a high crank velocity for Pmax. As seen previously,
Pmax of HA2 and LA2 boys were significantly lower than
those of HA1 and LA1 boys (see Fig. 1). Moreover, V0
was significantly lower in HA2 and LA2 boys than in HA1
and LA1 boys (Table 4). These observations might indicate
a lower proportion of type II fibers in HA2 and LA2 chil-
dren. We also noticed during the experiments that many
boys could not pedal properly, particularly at high velo-
city. 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 VO2max (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 P of prepu-
bertal boys of the same socioeconomic class. However,
regardless of altitude, poor socioeconomic and nutri-
tional conditions lead to lower power developed during
short-term maximal exercises. This cannot be fully ex-
plained by reduction in body size. Others factors, such as
a decrease in the proportion of muscle type II fibers be-
cause of nutritional stress and a reduced ability to per-
form on a bicycle because of coordination problems, are
also some possible explanations for this phenomenon.
However, this phenomenon needs further investigation.

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### Table 5. Pmax and P observed and calculated from equation of Bedu (unpublished data) in HA2 and LA2 boys

<table>
<thead>
<tr>
<th></th>
<th>HA2</th>
<th>Observed Values</th>
<th>Predicted Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pmax = 13.45 kg BW − 185</td>
<td>194±35</td>
<td>214±57</td>
</tr>
<tr>
<td></td>
<td>P = 8.67 kg BW − 106</td>
<td>133±34</td>
<td>151±36</td>
</tr>
<tr>
<td></td>
<td>Pmax = 8.34 kg BW + 4.72 cm H − 668</td>
<td>163±34</td>
<td>208±52</td>
</tr>
<tr>
<td></td>
<td>P = 5.62 kg BW + 7.6 yr-A + 2.15 cm H − 366</td>
<td>124±22</td>
<td>170±32</td>
</tr>
</tbody>
</table>

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


