Physical Fitness of Children Resident at High Altitude in Bolivia

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

Abstract

N. Fellmann, J. Coudert, H. Spielvogel, M. Bedu, P. Obert, G. Falgairette, E. Van Praagh, Physical Fitness of Children Resident at High Altitude in Bolivia. Int J Sports Med, Vol 13, Suppl 1, pp S92–S95, 1992.

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

1) Maximal oxgen consumption ($\dot{V}O_2max$) varies from 35 to 45 $ml \cdot min^{-1} \cdot kg^{-1}$ and maximal heart rate from 188 to 194 $beats \cdot min^{-1}$. These values are lower than those of their counterparts at low altitude (LA) by 10–20% and 10 – 15 $b \cdot min^{-1}$, respectively.

2) The anaerobic metabolism is not affected by chronic hypoxia if the nutritional conditions and pubertal development of HA and LA boys are the same. When related to percent of $\dot{V}O_2max$, submaximal O_2 debts are similar at HA and LA. After supramaximal exercise, maximal O_2 debts (45.7 ± 2.7 vs 45.9 ± 3.8 $ml \cdot kg^{-1}$) and blood lactate concentrations (7.6 ± 0.6 vs 6.5 ± 0.6 $mmol \cdot l^{-1}$) are also the same at HA and LA. No differences are observed between the 2 altitudes in ventilatory (60 vs 56% $\dot{V}O_2max$) and lactate (60 vs 65% $\dot{V}O_2max$) thresholds. The altitude of La Paz does not alter the anaerobic performance of a force-velocity test (from 6 to 10 $W \cdot kg^{-1}$) between the ages of 7 to 15 years but reduces by 14–17% the mean anaerobic power developed during a 30-s Wingate test. This decrease could be linked to a lower participation of glycolysis and aerobic metabolism at HA during this test.

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

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

Key words

Maximal oxygen consumption, anaerobic metabolism, malnutrition, puberty development

Int. J. Sports Med. 13 (1992) S92–S95

Introduction

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

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

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

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

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

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

I. Aerobic Performance

By direct method, using treadmill or cycle ergometer, the maximal oxygen consumption ($\dot{V}O_2max$) of untrained children living in La Paz varies from 35 to 45 $ml \cdot min^{-1} \cdot kg^{-1}$ according to the studies (7, 8, 11, 13) (see Figure 1). These values are of the same order of magnitude as found by Andersen (1) in 10–12-yr-old Ethiopian boys living at an altitude of 3,000 m (40 $ml \cdot min^{-1} \cdot kg^{-1}$).

At HA, $\dot{V}O_2max$ is reduced by 10–20% when compared with mean values in untrained LA children of the same age and socio-economic class, and from Amerindian or European families. A similar $\dot{V}O_2max$ decrease has been reported by Raynaud et al. (20) in adult men living in La Paz.

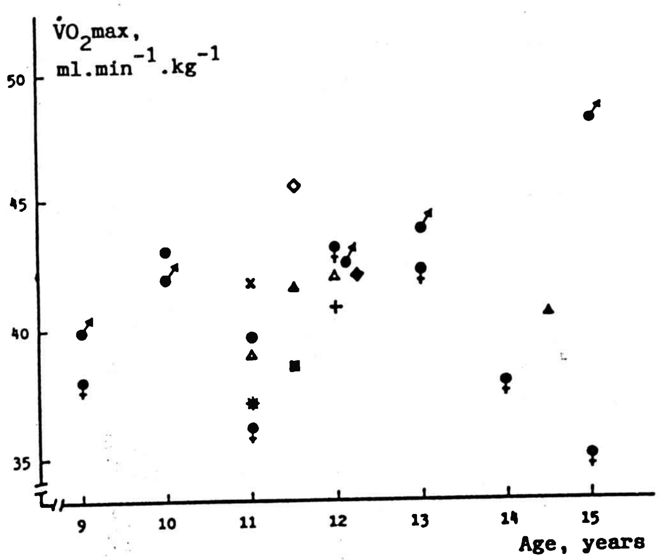

Fig. 1 Maximal oxygen consumption ($\dot{V}O_2$max) in children from high and low socio-economic background living in La Paz.

Children from high socio-economic background living in La Paz:
- ▲ Bedu (3): 11–12 and 14–15 yr-old boys (n = 15)
- • Coudert (unpublished data): 10–12 yr-old boys (n = 23)
- x Fellmann et al. (7): 10–13 yr-old boys (n = 11)
- + Fellmann et al. (8): 11–13 yr-old boys (n = 14)
- ●. Greksa et al. (11): 9–13 yr-old boys born in La Paz (n = 34)
- ■ Greksa et al. (11): 9–13 yr-old boys born at low altitude (n = 33)
- ♂ Greksa et al. (12): 9-15 yr-old trained boys (n = 17)
- ♀ Greksa et al. (12): 9–15 yr-old trained girls (n = 19)
- ◆ Greksa et al. (13): 11–13 yr-old boys (n = 14)

Children from low socio-economic background living in La Paz
- Δ Coudert (unpublished data): 11–13 yr-old boys (n = 33)
- Δ Obert et al. (18): 10–12 yr-old boys (n = 44)
- ◊ Greksa et al. (13): 11–12 yr-old Aymara boys (n = 13).

As in adults, the maximal heart rate (188–194 beat · min^{-1}) is reduced in HA boys by a mean of 10 b · min^{-1} (7, 8, 11, 13).

With training, $\dot{V}O_2$max can reach higher values: Greksa et al. (12) have observed 52 ml · min^{-1} · kg^{-1} in a 15-yr-old swimmer and 47 ml · min^{-1} · kg^{-1} in a 12-yr-old trained girl. However, $\dot{V}O_2$max tended to be 10–20% lower in the swimmers than in sea level athletes.

$\dot{V}O_2$max changes with age are similar at HA and LA. In untrained children living in La Paz, $\dot{V}O_2$max increases by 183 ml · min^{-1} · year^{-1} as at LA (Clermont-Ferrand, 330 m altitude) (3). No increase was observed at HA and LA in $\dot{V}O_2$max when related to body weight. In contrast, in swimmers, the increase with age in $\dot{V}O_2$max is higher than in sedentary groups, expressed either in absolute terms (+250 ml · min^{-1} · year^{-1}) or by body weight (+1.6 ml · min^{-1} · kg^{-1} · year^{-1}) (12). In line with these values, are the findings of Falgairette et al. (5) in children trained at LA.

Contrary to Frisancho's hypothesis on adults (10), the length of residence at high altitude during childhood does not alter the maximal aerobic power, $\dot{V}O_2$max does not differ significantly between boys (aged 8.8–13.1 yr-old) born at high altitude and 33 born at low altitude who migrated to La Paz between the age of 6 and 11 years (11).

A chronic marginal malnutrition has no influence on aerobic performance. No difference is observed between European boys from middle and upper-class families and Aymara boys (13). More recently, we found in La Paz that 11-yr-old boys from a poor socio-economic background exhibited a lower $\dot{V}O_2$max (in l·min^{-1}) than HA rich boys. However this $\dot{V}O_2$max decrease is due to a diminished muscle mass since the difference is eliminated when $\dot{V}O_2$max is expressed in ml · min^{-1} · kg^{-1} muscle weight. The same result is found at LA in the tropical area of Santa Cruz de la Sierra (Bolivia, 500 m)(18).

At the present time, there is no evidence in children to explain the decrease in $\dot{V}O_2$max at HA. from adults' data, the limiting factor could be the O_2 diffusion in muscle. The decrease in O_2 pressure gradient between capillaries and mitochondria (linked to the PaO_2 reduction) may induce a lower $\dot{V}O_2$max at HA (21).

II. Anaerobic Performance

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

The anaerobic metabolism evaluated by submaximal and maximal O_2 debts, blood lactate concentrations after maximal or supramaximal exercises, anaerobic ventilatory and lactate thresholds and maximal anaerobic power is not different between children living in La Paz and European or Bolivian children at LA (Table 1). However this is only true if the 2 groups belong to the same socio-economic backgrounds and have the same level of sexual maturation.

O_2 Debt (Table 1)

When related to % $\dot{V}O_2$max, the O_2 debt of 50 boys and girls aged 10 to 13 yrs, born and living in La Paz or residing for 3 yrs or more at HA, is similar to that of 25 French children at LA (7). In particular, maximal O_2 debts obtained after exercises of 115% maximal aerobic power intensity are the same at HA and LA (Table 1). These values correspond to literature data for untrained children of the same age living at LA (19). Moreover, $\dot{V}O_2$ kinetics during recovery are also the same at HA and LA, consistent with previous findings in adults acclimatized to La Paz altitude (20).

Blood lactate concentration ([L])

No difference is observed between HA and LA for [L] after maximal exercise (6.0 ± 0.3 vs 6.7 ± 0.5 mmol · l^{-1}) and supramaximal exercise (Table 1), and for linear relationships between maximal O_2 debt and [L] (7).

However the interpretation of anaerobic data must take into account the sexual maturation of the children compared. Indeed, [L] is higher in 12-yr-old boys at HA than in LA boys of the same chronological age but with delayed gonadal development (8).

Table 1 Data on anaerobic metabolism in boys from a high socio-economic background living at high altitude (La Paz 3,700 m) (references 2, 6, 7).

Tests		Units	High Altitude boys	Low Altitude boys (France, 330 m)	Significance	Age yrs
Supramaximal exercise (115% MAP)	Maximal O_2 debt [L]	l STPD	1.64 ± 0.14	1.73 ± 0.16	NS	10–13
		$ml \cdot kg^{-1}BW$	45.7 ± 2.7	45.9 ± 3.8	NS	
		$mmol \cdot l^{-1}$	7.6 ± 0.6	6.5 ± 0.6	NS	
Maximal Exercise	Ventilatory threshold	l O_2 STPD	1.01 ± 0.04	1.32 ± 0.07	***	11–13
		%$\dot{V}O_2$max	63.6 ± 1.6	64.6 ± 2.7	NS	
	Lactate threshold	l O_2 STPD	0.92 ± 0.04	1.14 ± 0.03	**	
		%$\dot{V}O_2$max	59.7 ± 2.5	55.8 ± 1.9	NS	
Force Velocity test	Maximal anaerobic power	$W \cdot kg^{-1}BW$	6.0 ± 0.6	5.9 ± 1.2	NS	7–8
			8.2 ± 1.4	9.1 ± 1.3	NS	11–12
			9.7 ± 1.9	10.8 ± 1.2	NS	14–15
30-s Wingate test	Mean Power	$W \cdot kg^{-1}BW$	4.1 ± 0.9	4.6 ± 1.1	NS	7–8
			5.7 ± 1.0	6.9 ± 1.0	**	11–12
			6.7 ± 1.5	7.7 ± 0.9	*	14–15
	$\dot{V}O_2$	ml STPD	309 ± 63	363 ± 90	NS	7–8
			452 ± 84	587 ± 83	***	11–12
			708 ± 130	936 ± 156	***	14–15
	[L]	$mmol \cdot l^{-1}$	3.4 ± 1.5	6.5 ± 2.2	***	7–8
			6.4 ± 1.4	7.7 ± 2.3	NS	11–12
			7.5 ± 2.0	8.2 ± 1.3	NS	14–15

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

Anaerobic thresholds

Although $\dot{V}O_2$ at ventilatory (VT) and lactate (LT) thresholds are lower at HA, VT and LT are the same at both altitudes when related to % $\dot{V}O_2$max (6) (Table 1).

Maximal anaerobic power

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

On the contrary, the "mean power" and the "peak power" developed during a 30-s Wingate test are reduced at HA by 14–17% from the ages 10–11 up to 15 (2) (Table 1). Two possible explanations for the decrease in Wingate performance at HA have been suggested. $\dot{V}O_2$ during the 30-s test is reduced in HA boys by 17–20%, which is close to the reduction in $\dot{V}O_2$max usually observed at this altitude (Table 1). Since the relative energy contribution of aerobic metabolism during a Wingate test is high, particularly in children, a reduced aerobic performance at HA can contribute to a lower performance during the Wingate test. The decrease in power can also be linked to a reduced participation of glycolysis at HA suggested by lower [L] after the test (Table 1).

As for $\dot{V}O_2$max, changes during growth of anaerobic power developed during the 2 tests are the same at HA and LA i.e. a mean increase of 70% between 7 to 15 yrs (2).

In contrast to aerobic performance, marginally undernourished boys, living in poor districts of La Paz, developed during short-term intense exercises lower power than well nourished children from a high socio-economic background and living at the same altitude (18). These results and those for $\dot{V}O_2$max strengthen previous findings in adults after hypocaloric diet under normoxic conditions. Russel et al. (22) found that the size of the slow-twitch fibres in calf and thigh muscles is better preserved than that of the fast fibres.

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

References

1 Andersen, K. L.: The effect of altitude variation on the physical performance capacity of Ethiopian men. Part II. Development of physical performance during adolescence, in Seliger V. (ed): Physical Fitness. Prague: Charles University, 1973, pp 34–36.

2 Bedu, M., Fellmann N., Spielvogel H., Falgairette G., Van Praagh E., Coudert J.: Force-Velocity and 30-s Wingate tests in boys at high and low altitudes. *J Appl Physiol* 70: 1031–1037, 1991.

3 Bedu M.: Epreuve de force-vitesse et test de Wingate chez l'enfant à haute et basse altitudes. Thèse d'Etat de Biologie Humaine. Université d'Auvergne, Clermont-Ferrand 1992.

4 Di Prampero P. E., Mognoni P., Veicsteinas S. A.: The effects of hypoxia on maximal anaerobic alactic power in man, in Brendel D., Zink J. (eds): High Altitude Physiology and Medicine. New-York, Springer Verlag, 1982, pp 88–93.

5 Falgairette G.: Evolution de la puissance maximale aérobie de l'enfance à l'age adulte: influence de l'activité physique et sportive. Revue des Sciences et Techniques des Activités Physiques et Sportives 10: 43–58, 1989.

6 Falgairette G., Van Praagh E., Fellmann N., Bedu M., Spielvogel H., Coudert J.: Effect of high altitude chronic hypoxia on lactate and ventilatory thresholds in healthy young boys, in Oseid S., Carlsen K. (eds): Children and Exercise XIII. Champaign Il, Human Kinetics, 1989, pp 145–154.

7 Fellmann N., Bedu M., Spielvogel H., Falgairette G., Van Praagh E., Coudert J.: Oxygen debt in submaximal and supramaximal exercise in children at high and low altitude. *J Appl Physiol* 60: 209–215, 1986.

8 Fellmann N., Bedu M., Spielvogel H., Falgairette G., Van Praagh E., Jarrige J. F., Coudert J.: Anaerobic metabolism during pubertal development at high altitude. *J Appl Physiol* 64: 1382–1386, 1988.

9 Ferretti G., Hauser H., Di Prampero P. E.: Maximal muscular power before and after exposure to chronic hypoxia. *Int J Sports Med* 11 (suppl 1): 531–534, 1990.

10 Frisancho A. R., Martinez C., Velasquez T., Sanchez J., Montoye H.: Influence of developmental adaptation on aerobic capacity at high altitude. *J. Appl Physiol* 34: 176–180, 1973.

11 Greksa L. P., Haas J. D.: Physical growth and maximal work capacity in preadolescent boys at high altitude. *Human Biology* 54: 677–695, 1982.

12 Greksa L. P., Haas J. D., Leatherman T. L., Spielvogel H., Paz Zamora M., Paredes-Fernandez L., Moreno-Black G.: Maximal aerobic power in trained youths at high altitude. *Annals of Human Biology* 9: 201–209, 1982.

13 Greksa L., Spielvogel H., Paredes-Fernandez L.: Maximal exercise capacity in adolescent European and Amerindian high-altitude natives. *Am J Phys Anthrop* 67: 209–216, 1985.

14 Howald D., Pette D., Simoneau J., Uber A., Hoppeler H., Ceretelli P.: Effects of chronic hypoxia on muscle enzyme activities. *Int J Sports Med* 11: 510–514, 1990.

15 McLellan T. M., Kavanagh M. F., Jacobs I.: The effect of hypoxia on performance during 30s or 45s of supramaximal exercise. *Eur J Appl Physiol* 60: 155–161, 1990.

16 Linnarsson D.: Muscle metabolites and oxygen deficit with exercise in hypoxia and hyperoxia. *J Appl Physiol* 36: 399–402, 1974.

17 Matheson G., Allen P., Ellinger D., Hanstock C., Gheorghin D., McKenzie D., Stanley C., Parkhouse W., Hochachka P.: Skeletal muscle metabolism and work capacity: a 31P-NMR study of Andena natives and lowlanders. *J Appl Physiol* 70: 1963–1976, 1991.

18 Obert P., Bedu M., Fellmann N., Falgairette G., Van Praagh E., Kemper H., Post B., Parent G., Quintanilla A., Tellez V., Coudert J.: Anthropometric and bioenergetic characteristics in highland Bolivian children of low and high socio-economic status, in Coudert J., Van Praagh E. (eds): Children and Exercise XVI. Paris, Masson, 213–216, 1992.

19 Paterson D. H., Cunningham D. A., Bumstead L. A.: Recovery O_2 and blood lactic acid: longitudinal analysis in boys aged 11 to 15 years. *Eur J Appl Physiol* 55: 93–99, 1986.

20 Raynaud J., Martineaud J. P., Bordachar J., Tillore M. C., Durand J.: Oxygen deficit and debt in submaximal exercise at sea level and high altitude. *J Appl Physiol* 37: 43–48, 1974.

21 Roca J., Hogan M. C., Story D., Debout D. E., Haab P., Gonzales R., Veno O., Wagner P. D.: Evidence for tissue diffusion limitation of $\dot{V}O_2max$ in normal humans. *J Appl Physiol* 67: 291–299, 1989.

22 Russel D., Walker P., Leiter L., Sima A., Tanner W., Mickle D., Whitwell J., Marliss E., Jeejeebhoy K.: Metabolic and structural changes in skeletal muscle during hypocaloric dieting. *Am J Clin Nutr* 39: 503–513, 1984.

N. Fellmann

Laboratory of Physiology and Sports Biology
Faculty of Medicine
63001 Clermont-Ferrand
France