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# Identifying the ideal body size and shape characteristics associated with children's physical performance tests in Peru

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**We used allometric models to identify the optimal body size/shape characteristics associated with physical and motor performance tests in Peruvian schoolchildren. The sample consisted of 3624 subjects (1669 boys and 1955 girls) aged 11–17 years from 31 public schools belonging to four cities located in the three natural regions in central Peru. Motor performance included 12-min run, standing long jump, grip strength, curl-ups, shuttle run, and sit and reach. The reciprocal Ponderal index (RPI), a characteristic sometimes referred to as the somatotype "ectomorphy," was found to be the most suitable body shape indicator associated with 12-min run, standing long jump, curl-up, and shuttle run performance. A positive maturation offset parameter was also associated with greater standing long jump, grip strength, shuttle run, and sit-and-reach performances. With the exception of the sit-and-reach flexibility, sex differences are pervasive in all tests favoring boys. Rainforest schoolchildren are best performers in the power and flexibility tests, whereas those from high altitude were superior in the 12-min endurance test even after taking their much lighter body size characteristics into account. This latter finding suggests that living at high altitude in Peru benefits children's endurance performance both before and even after controlling for differences in the confounding variable of body size/shape.**

The size and shape of the body show systematic variations in modern humans as well as in our ancestors as a result of complex interactions between genetic factors in the long term, as well as the environment, including geo-climate, altitude, nutrition, and disease factors just to name a few (Ruff, 2002). Likewise, physical and motor performance is similarly determined, and it has been suggested that up to 40% of its total variation may be accounted for by genetic factors that are differentially expressed in the processes of growth, motor development, and biological maturation (Bouchard, 1986). In the same vein, physical and motor performance is influenced by a myriad of environmental factors, although the extent of their general effect sizes is variable (Malina et al., 2004).

The interpretation of the influence of body size, composition, and shape in physical and motor performance components of children and adolescents of different socioeconomic and cultural strata is a matter of continuing debate (Malina et al., 1987; Slaughter & Christ, 1995). The allometric approach is currently viewed as a suitable model to help solve this issue given its sound theoretical basis, biologically driven, and its elegant and versatile statistical methodology (Nevill, 1997; Nevill et al., 2004). This technique often provides a truly dimensionless expression of data that can be used in subsequent comparisons between groups that differ in size, structure, and body shape (Nevill et al., 2009). Furthermore, its modeling techniques properly address the effects of age and sex differences in growth and biological maturation in motor performance interpretation (Malina et al., 2004). As body size and shape may confound human motor performance (Nevill & Holder, 2000), adjusting physical and motor performance measures to body physique components would allow meaningful individual and group comparisons; it also enables the construction of normative reference standards (Pua, 2006).

Human populations have settled in regions with diversified geographical features manifesting in different levels of atmospheric pressure, solar radiation, humidity, and temperature (Hiernaux, 1988). In South America, the territory of Peru extends along three natural areas: (a) the coast or coastal desert, located between the western mountain and the Pacific Ocean, corresponding to 11.7% of the national territory with a subtropical desert climate; (b) the Saw or Andean region localized in the central part of the Andes mountain comprising 28.0% of the national territory with a high mountain and mountain climate; (c) the jungle or Amazon region being the largest of the Peruvian territory that occupies ~60.3% of its surface with warm and rainy tropical climate; (d) in addition, the current Peruvian population is mestizo and ethnically consists of different groups: native (45%); mestizos natives with ancestors of Europeans (37%); whites (15%); black, Japanese, Chinese, and others (3%) (Instituto Nacional de Estadística e Informática, 2005). Various studies have considered the effects of altitude on morphological and physiological traits that affect work efficiency and general motor performance of Andean populations (Mueller et al., 1978; Frisancho, 1988; Leonard et al., 1990; Rupert & Hochachka, 2001; Greksa, 2006). To the best of our knowledge, no such data to scale physical and motor performance for differences in body size and shape exist in Peruvian children/adolescents residing in diverse geographic areas. In this sense, the purpose of this study was to use allometric models to identify the optimal characteristics of body size and shape, associated with Peruvian children and adolescents residing in different geographical locations in their physical and motor performance.

## Methods

### Sample

The present cross-sectional sample comes from the Healthy and Optimistic Growth Study, which investigates growth, development, and health of children, adolescents, and their families. A stratified random sample, having schools as primary strata, of 3624 adolescents (1669 boys and 1955 girls) aged 11–17 years was collected from 31 public schools belonging to four cities located in the three natural regions of central Peru: in the coast, Barranco (58 m), which forms part of the province of Lima; in the Saw, Junín district (4107 m); in the province of the same name; and in the jungle, the districts of La Merced and San Ramon (751 m) that have a geographical continuity and integrate the Chanchamayo province (Table 1). All data were collected between March 2009 and July 2011 during the same time periods to avoid seasonality effects. After initial political, educational, and health contacts in each city, formal permission was asked from school authorities participating in the study. Written consent from parents and assent from children was obtained after full explanation of all procedures. The ethical committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV) approved the investigation.

### Anthropometry

All measurements were made according to standardized techniques (Lohman et al., 1988). Height and sitting height was measured to the nearest 0.1 cm with a portable stadiometer (Sanny, Model ES-2060, American Medical do Brasil, Ltda, São Bernardo do Campo, São Paulo, Brasil); body mass was measured at the nearest 0.1 kg using a digital scale (Pesacon, Model 320KL, Pelstar LLC, Health o meter, Inc., Illinois, USA). Body mass index (BMI) was obtained by the usual ratio of body mass to height ($kg/m^2$) and reciprocal Ponderal index (RPI) ($height \cdot mass^{-0.333}$) recorded in the units ($cm/kg^{0.333}$).

### Maturity offset

Maturity offset predicts time before or after age at peak height velocity, and is a non-invasive method with few cultural restrictions. Very simply, sex-specific equations were used with age, body mass, height, sitting height, and leg length as predictors (Mirwald et al., 2002). The maturity offset equation estimates the distance each subject is from their expected age (in years) of attainment of peak of high velocity (PHV). The value is expressed in years (either + or −) from PHV. Note that by incorporating the maturity offset into our model, the use of a non-linear exponential function is capable of modeling the increasing/decreasing rate in the way maturity offset affects motor performance in addition to other confounding variables such as age.

### Physical performance

Four tests are part of the EUROFIT battery (Committee of Experts on Sports Research, 1993) that were used to assess static and explosive muscle strength, flexibility, and speed/agility; abdominal muscular endurance was evaluated with the test curl-up's of the Fitnessgram battery (Welk & Meredith, 2000), and cardiorespiratory endurance was evaluated by testing AAPHERD (American Alliance for Health, 1980) battery 12-min run.

1. The 12-min run test. In a previously delimited field, schoolchildren in group run/walk the maximum possible distance in 12 min.
2. The standing long jump test. Jumping with feet together and without a preparatory run. The maximum jumping distance is recorded. Two trials were given and the best score was recorded as the maximum jump distance in centimeters.
3. The grip strength test. The adolescents were instructed to squeeze a calibrated hand dynamometer (Takei TKK 5401, Tokyo, Japan) with maximal force. All schoolchildren performed two trials with each hand. The best trial from each hand was recorded in kilograms and was used to compute the mean muscle strength. The handle length was adjusted to control for variations in hand size.

Table 1. Number of schoolchildren in the three areas of central Peru according to age and sex

| Age (years) | Sea level | | Rainforest area | | High altitude | | All | |
|---|---|---|---|---|---|---|---|---|
| | Barranco (58 m) | | Chanchamayo (751 m) | | Junín (4107 m) | | | |
| | Girls | Boys | Girls | Boys | Girls | Boys | | |
| 11 | 111 | 114 | 43 | 25 | 31 | 29 | 185 | 168 |
| 12 | 92 | 119 | 165 | 92 | 76 | 67 | 333 | 278 |
| 13 | 69 | 64 | 190 | 124 | 46 | 63 | 305 | 251 |
| 14 | 125 | 102 | 168 | 110 | 76 | 69 | 369 | 281 |
| 15 | 110 | 142 | 137 | 144 | 65 | 60 | 312 | 346 |
| 16 | 139 | 82 | 123 | 114 | 68 | 57 | 330 | 253 |
| 17 | 57 | 38 | 35 | 38 | 29 | 16 | 121 | 92 |
| All | 703 | 661 | 861 | 647 | 391 | 361 | 1955 | 1669 |

4. The curl-up test. From established positioning according to the Fitnessgram protocol (Welk & Meredith, 2000), the number of elevations and descents of the trunk properly performed up to a limit of 75 are recorded.
5. The shuttle run test. Each adolescent performs five cycles (round trip) at maximum speed between two lines separated by 5 m. The adolescents conducted the test in pairs.
6. The sit-and-reach test. With the adolescent sitting on the floor and using a standardized wooden stand (Committee of Experts on Sports Research, 1993), the maximum distance achieved with the tip of the middle fingers through previous flexion of the trunk. Two trials were allowed and the score was recorded in centimeters.

### Data quality control

Data quality control was assessed in three steps: the first corresponded to a pilot study carried out in the facilities of the UNE EGyV in March 2009 with the presence of the mentors of this project: G. B. and J. M.; in the second phase, a reliability in field procedure was used, where three to five students were randomly selected on alternating evaluation days. Technical error of measurement (TEM) for height and body mass, and analysis of variance (ANOVA)-based intraclass correlations ($R$) and corresponding 95% confidence intervals (95% CIs) were used to estimate test–retest reliabilities for all motor performance tests: 12-min run test, $R = 0.87$ (95% CI: 0.82–0.91); standing long jump, $R = 0.98$ (95% CI: 0.97–0.98); grip strength test, $R = 0.96$ (95% CI: 0.94–0.97); curl-ups test, $R = 0.91$ (95% CI: 0.88–0.93); shuttle run test, $R = 0.88$ (95% CI: 0.85–0.91); and flexibility test, $R = 0.89$ (95% CI: 0.86–0.92). With anthropometric measures, height TEM = 0.2 cm, $R = 0.98$ (95% CI: 0.97–0.99); body mass TEM = 0.1 kg, $R = 0.98$ (95% CI: 0.97–0.99), and sitting height TEM = 0.1 cm, $R = 0.98$ (95% CI: 0.97–0.99). No significant differences between test and retest means were observed in any variable. The final step consisted in checking for errors in data entry, inconsistent data, and exploratory data analysis was carried out in SPSS v.20 (IBM SPSS Corporation, New York, USA).

### Statistical methods

In order to identify the most appropriate body size and shape characteristics as well as any categorical differences (sex, age, etc.) associated with a variety of physical performance variables, we adopted the following multiplicative model with allometric body size components, similar to that used to model the physical performance variables of Greek children (Nevill et al., 2009):

$$Y = a \cdot \text{mass}^{k_1} \cdot \text{height}^{k_2} \cdot \exp(b \cdot \text{maturity-offset}) \cdot \varepsilon. \quad [1]$$

This model has the advantages of having proportional body size components and the flexibility of a maturity offset estimate within an exponential term that will ensure that the measure of physical performance ($Y$) will always remain non-negative irrespective of the subjects' maturity offset estimate. Note that "ε," the multiplicative error ratio, also assumes the error will increase in proportion to the physical performance variable $Y$.

The model (eqn. [1]) can be linearized with a log transformation. A linear regression analysis on log($Y$) can then be used to estimate the unknown parameters of the log-transformed model:

$$\begin{aligned}\log(Y) = \log(a) + k_1 \cdot \log(\text{height}) + k_2 \cdot \log(\text{mass}) \\ + b \cdot (\text{maturity-offset}) + \log(\varepsilon)\end{aligned} \quad [2]$$

Further categorical or group differences within the population, e.g., sex, age (entered as discrete categories, 11–17 years), and where the children lived in Peru (sea level, rainforest area, and high altitude), can be explored by allowing the constant intercept parameter "log($a$)" in eqn. [2] to vary for each group (by introducing them as fixed factors within the analysis of covariance). The significance level was set at $P < 0.05$.

## Results

Table 2 presents ANOVA and Cohen's effect size results of adolescents' growth, maturity offset, and motor performance among the three regions. Boys and girls living in high-altitude areas are shorter, lighter, and have a lower BMI, together with a lower mean maturity offset than those from other regions; similarly, their motor performance is also lower than boys and girls from other regions, with the exception of the 12-min run where they outperform them. Cohen effect sizes ranged from 0.00 to 0.84 in anthropometry and from 0.03 to 2.77 in motor performance tasks.

### The 12-min run test

The multiplicative model relating the distance run to the body size components was found to be:

$$\text{Distance}\,(\text{m}) = a \cdot \text{mass}^{-0.113} \cdot \text{height}^{0.267}$$

with the mass and height exponents being $k_1 = -0.113$ [standard error of estimate (SEE) = 0.025] and $k_2 = 0.267$ (SEE = 0.102), respectively, but with no significant effect due to the maturation offset having controlled for differences in mass, height, sex, age, etc. The adjusted coefficient of determination, adjusted $R^2$ was 40.1% with the log-transformed error ratio being 0.192% or 21.2%, having taken antilogs. The constant "$a$" varied significantly with the three main effects sex, age, and where the children lived in Peru (sea level, rainforest area, and high altitude) and all interactions between these categorical variables (all $P < 0.01$). Note that it is problematic to draw inference from main effects when higher order interactions are detected. The key interaction between sex and age on distance run (log transformed) is plotted in Fig. 1(a). Clearly, the figure illustrates the overall increase in distance run in 12 min with older children (age main effect, $P < 0.01$), but the interaction indicates a greater distance run by boys compared with girls in older children ($P < 0.01$).

A second key interaction between where the children live in Peru and sex on distance run (log transformed) is given in Fig. 2(a). The figure illustrates a geographical region main effect with the rise in distance run in 12 min increasing from seal level to the rain forest, with the greatest distance being run in the high-altitude regions of Peru ($P < 0.01$). The interaction suggests that this progression is not consistent when comparing boys with girls, with the gap between girls and boys being greater in the rain forest compared with other regions of Peru ($P < 0.01$).

The body mass and height components associated with the distance run for the above model can be rear-

Table 2. Results of mean differences between the three geographically differentiated areas in Peru central region for somatic and physical performance characteristics of schoolchildren from both sexes aged 11–17 years: sea level (1), rainforest area (2), and high altitude (3)

| Characteristics | Boys ($n = 1669$) | | | | | | | Girls ($n = 1955$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sea level | Rainforest area | High altitude | Level altitude difference | | | Cohen's effect size | Sea level | Rainforest area | High altitude | Level altitude difference | | | Cohen's effect size |
| | Mean ± SD | Mean ± SD | Mean ± Sd | *F* | *P* | Dif | | Mean ± SD | Mean ± SD | Mean ± SD | *F* | *P* | Dif | |
| Somatic | | | | | | | | | | | | | | |
| Age (years) | 13.7 ± 1.9 | 14.2 ± 1.6 | 13.8 ± 1.7 | 13.9 | 0.001 | 1 < 2; 2 > 3 | $(0.05 \le d \le 0.28)$ | 14.0 ± 1.9 | 13.8 ± 1.6 | 14.0 ± 1.8 | 2.0 | 0.131 | NS | $(0.00 \le d \le 0.12)$ |
| Body mass (kg) | 54.2 ± 12.3 | 48.2 ± 9.8 | 44.7 ± 9.4 | 103.0 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.36 \le d \le 0.84)$ | 50.3 ± 9.4 | 47.0 ± 8.5 | 44.8 ± 8.1 | 54.8 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.26 \le d \le 0.61)$ |
| Height (cm) | 157.1 ± 11.2 | 154.2 ± 9.6 | 152.4 ± 10.8 | 26.1 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.18 \le d \le 0.43)$ | 151.5 ± 6.4 | 150.0 ± 5.8 | 148.7 ± 6.3 | 28.0 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.22 \le d \le 0.44)$ |
| BMI (kg/m$^2$) | 21.8 ± 3.4 | 20.1 ± 2.7 | 19.0 ± 2.0 | 116.8 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.45 \le d \le 0.94)$ | 21.8 ± 3.3 | 20.8 ± 3.2 | 20.2 ± 2.7 | 39.7 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.20 \le d \le 0.52)$ |
| Sitting height (cm) | 83.1 ± 6.1 | 82.8 ± 5.6 | 82.1 ± 5.7 | 3.7 | 0.025 | 1 > 3 | $(0.05 \le d \le 0.17)$ | 81.7 ± 3.9 | 81.7 ± 3.5 | 81.1 ± 3.7 | 4.0 | 0.018 | 1 > 3; 2 > 3 | $(0.00 \le d \le 0.17)$ |
| RPI (cm/kg$^{-0.333}$) | 41.8 ± 2.2 | 42.6 ± 1.8 | 43.2 ± 1.3 | 68.1 | 0.001 | 1 < 2; 1 < 3; 2 < 3 | $(0.37 \le d \le 0.73)$ | 41.3 ± 2.0 | 41.8 ± 2.0 | 42.1 ± 1.7 | 24.8 | 0.001 | 1 < 2; 1 < 3 | $(0.16 \le d \le 0.42)$ |
| Maturity offset | 0.6 ± 1.8 | 0.7 ± 1.6 | 0.3 ± 1.6 | 5.7 | 0.003 | 1 > 3; 2 > 3 | $(0.06 \le d \le 0.25)$ | 0.8 ± 1.2 | 0.6 ± 1.0 | 0.6 ± 1.2 | 4.5 | 0.011 | 1 > 2; 1 > 3 | $(0.00 \le d \le 0.18)$ |
| Physical and motor performance | | | | | | | | | | | | | | |
| 12-min run test (m) | 1438.6 ± 391.2 | 1632.3 ± 320.2 | 1993.8 ± 403.8 | 287.0 | 0.001 | 1 < 2; 1 < 3; 2 < 3 | $(0.54 \le d \le 1.40)$ | 1281.6 ± 239.3 | 1328.4 ± 298.5 | 1666.9 ± 244.7 | 248.4 | 0.001 | 1 < 2; 1 < 3; 2 < 3 | $(0.17 \le d \le 1.60)$ |
| Horizontal jump test (cm) | 153.4 ± 29.1 | 145.4 ± 26.1 | 138.9 ± 19.7 | 20.7 | 0.001 | 1 > 2; 1 > 3; 2 > 3 | $(0.27 \le d \le 0.55)$ | 123.0 ± 20.2 | 124.1 ± 21.6 | 116.7 ± 11.7 | 38.5 | 0.001 | 1 > 3; 2 > 3 | $(0.05 \le d \le 0.39)$ |
| Grip strength test (kg) | 25.13 ± 8.7 | 28.1 ± 7.9 | 23.9 ± 8.0 | 7.0 | 0.001 | 1 < 2; 2 > 3 | $(0.15 \le d \le 0.53)$ | 19.5 ± 4.4 | 19.8 ± 4.1 | 18.9 ± 4.6 | 33.2 | 0.001 | 2 > 3 | $(0.07 \le d \le 0.21)$ |
| Curls test (n) | 49.3 ± 19.9 | 54.9 ± 18.8 | 48.7 ± 16.4 | 13.7 | 0.001 | 1 < 2; 2 > 3 | $(0.03 \le d \le 0.35)$ | 37.2 ± 18.4 | 36.7 ± 17.7 | 31.9 ± 13.6 | 19.3 | 0.001 | 1 > 3; 2 > 3 | $(0.03 \le d \le 0.32)$ |
| Shuttle run test (s) | 22.1 ± 3.0 | 20.9 ± 1.6 | 26.1 ± 2.3 | 569.2 | 0.001 | 1 > 2; 1 < 3; 2 < 3 | $(0.50 \le d \le 2.77)$ | 25.1 ± 3.3 | 23.0 ± 1.9 | 28.2 ± 2.1 | 562.1 | 0.001 | 1 > 2; 1 < 3; 2 < 3 | $(0.80 \le d \le 2.65)$ |
| Flexibility test (cm) | 19.8 ± 6.7 | 26.0 ± 6.5 | 20.9 ± 5.3 | 36.9 | 0.001 | 1 < 2; 1 < 3; 2 > 3 | $(0.18 \le d \le 0.94)$ | 24.1 ± 6.8 | 24.8 ± 6.7 | 21.5 ± 5.7 | 166.6 | 0.001 | 1 > 3; 2 > 3 | $(0.10 \le d \le 0.52)$ |

BMI, body mass index; RPI, reciprocal Ponderal index; SD, standard deviation.

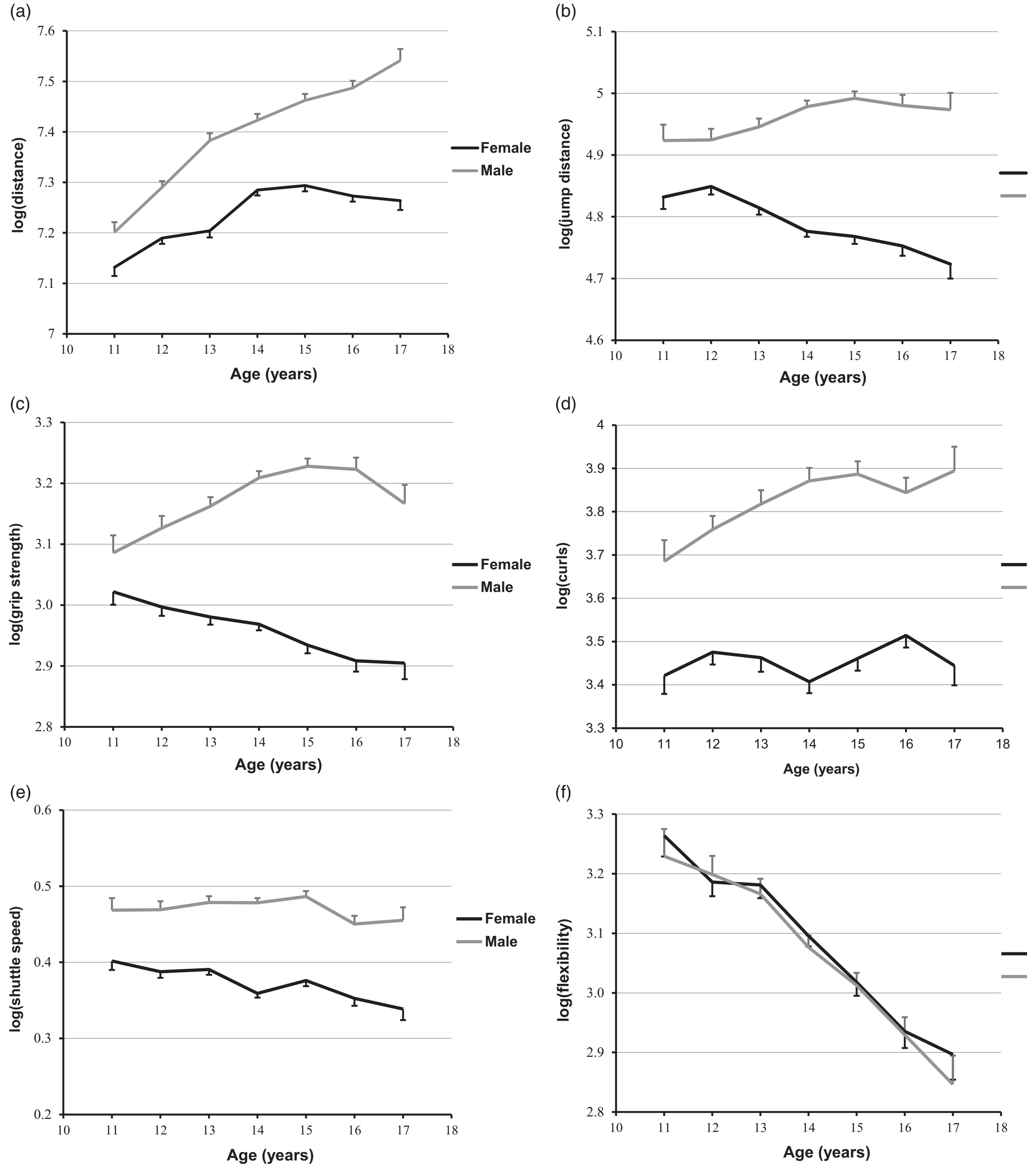

*Fig. 1.* Mean (±standard error of estimate) of log-transformed variables: distance run in 12 min (a), standing long jump (b), grip strength (c), curl-up (d), shuttle run speed (e), and sit-and-reach (f), respectively, by age and gender.

ranged and expressed as a height-to-mass ratio within a curvilinear power function as follows:

$$\text{mass}^{-0.113} \cdot \text{height}^{0.267} = \left(\text{height} \cdot \text{mass}^{-0.423}\right)^{0.267}$$

because $\text{mass}^{-0.113} = (\text{mass}^{-0.423})^{0.267}$. The 95% CI for the rearranged/rescaled mass exponent –0.423 is (–0.604 to –0.240). Note that this height-to-body mass ratio is similar to the RPI = height · $\text{mass}^{-0.333}$, because the 95% CIs encompass –0.333.

## The standing long jump test

The multiplicative model relating the standing long jump distance by the children to the body size components and maturity offset estimate was found to be:

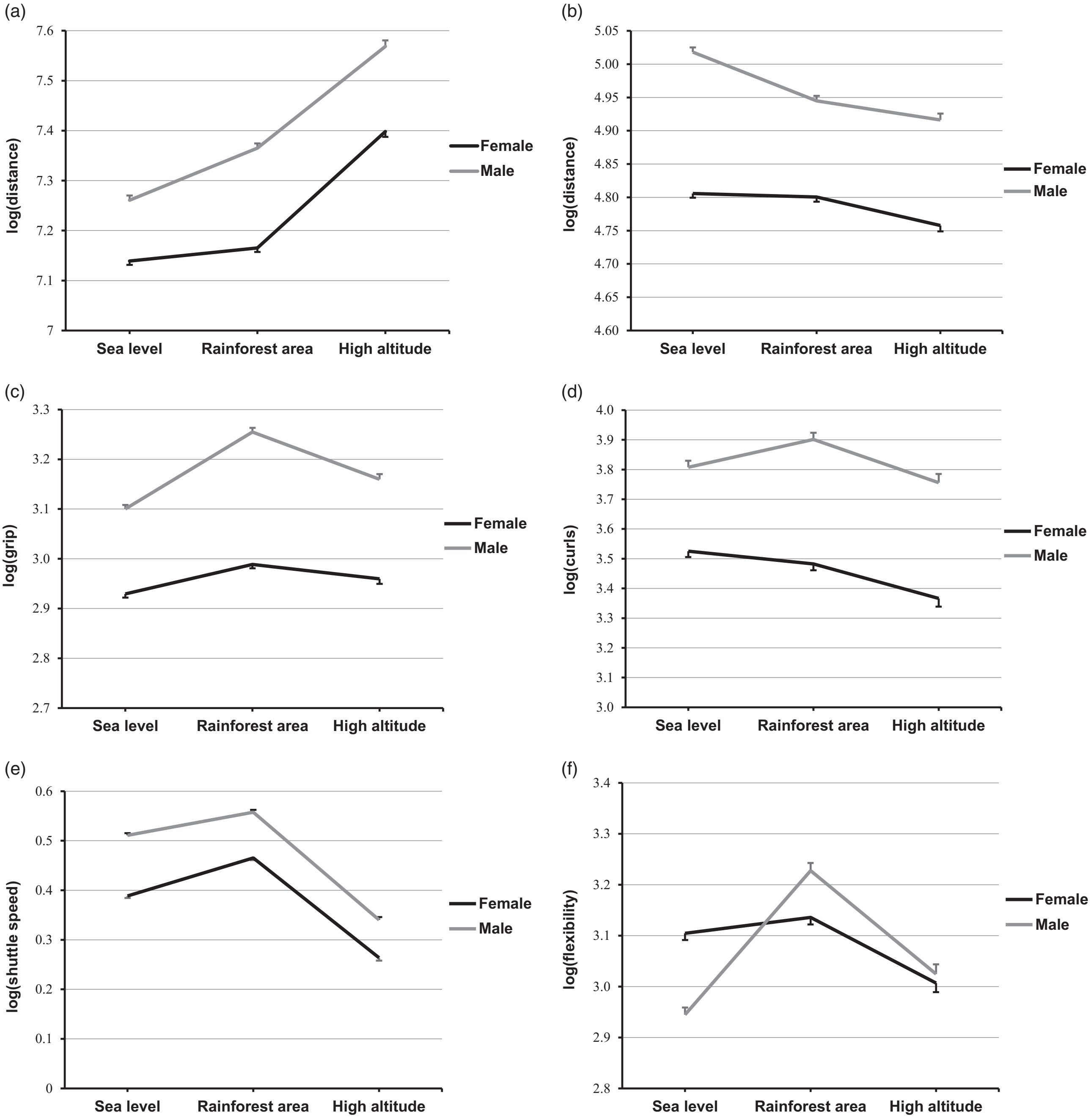

*Fig. 2.* Mean (±standard error of estimate) of log-transformed variables: distance run in 12 min (a), standing long jump (b), grip strength (c), curl-up (d), shuttle run speed (e), and sit-and-reach (f), respectively, by geographical area and gender.

$$\text{Jump distance}\,(\text{cm}) = a \cdot \text{mass}^{-0.268} \cdot \text{height}^{0.735} \cdot \exp(0.039 \cdot \text{maturity-offset})$$

with the mass and height exponents being $k_1 = -0.268$ (SEE = 0.026) and $k_2 = 0.735$ (SEE = 0.104), respectively, with a significant maturation offset parameter $b = 0.039$ (SEE = 0.011). The adjusted coefficient of determination, adjusted $R^2$ was 36.9% with the log-transformed error ratio being 0.155% or 16.7%, having taken antilogs. The constant "*a*" varied by sex, age, and where the children lived in Peru (sea level, rainforest area, and high altitude) and all interactions between the categorical variables ($P < 0.01$). The interaction between sex and age on jump distance (log transformed) is plotted in Fig. 1(b). The figure clearly illustrates that jump performances increase for boys but declines with girls in the older age groups ($P < 0.01$). The interaction between where the children live in Peru and sex on jumping distance (log transformed) is given in Fig. 2(b). The figure illustrates a trend in jump performance with the greatest jumps being at sea level, followed by the rain forest, with the smallest jump distance being in the high-altitude regions of Peru ($P < 0.01$). The interaction suggests that this progression is not consistent when comparing boys with girls, with the gap between girls and boys being smaller in the rain forest compared with other regions of Peru ($P < 0.01$).

The body mass and height components associated with the horizontal jump distance for the above model can be rearranged and expressed as a height-to-mass ratio within a curvilinear power function as follows:

$$\text{mass}^{-0.268} \cdot \text{height}^{0.735} = \left(\text{height} \cdot \text{mass}^{-0.365}\right)^{0.735}$$

because $\text{mass}^{-0.268} = (\text{mass}^{-0.365})^{0.735}$. The 95% CI for the rearranged/rescaled mass exponent −0.365 is (−0.426 to −0.165). Note that this height-to-body mass ratio is similar to the $\text{RPI} = \text{height} \cdot \text{mass}^{-0.333}$, because the 95% CIs encompass −0.333.

### The grip strength test

The multiplicative model relating grip strength (kg) to the body size components and maturity offset estimate was found to be:

$$\text{Grip strength (kg)} = a \cdot \text{mass}^{0.248} \cdot \text{height}^{1.192} \cdot \exp(0.084 \cdot \text{maturity-offset})$$

with the mass and height exponents being $k_1 = 0.248$ (SEE = 0.029) and $k_2 = 1.192$ (SEE = 0.117), respectively, with a significant maturation offset parameter $b = 0.084$ (SEE = 0.013). Note that the mass and height exponents are both positive. The adjusted coefficient of determination, adjusted $R^2$ was 69.7% with the log-transformed error ratio being 0.176% or 19.3%, having taken antilogs. The constant "*a*" varied by sex, age, and where the children lived in Peru (sea level, rainforest area, and high altitude) and many interactions between the categorical variables ($P < 0.01$). The interaction between sex and age on grip strength (log transformed) is plotted in Fig. 1(c). As with jump performance, the figure illustrates that boys' grip strength increases with older boys but the girls declines ($P < 0.01$). The interaction between where the children live in Peru and sex on grip strength (log transformed) is given in Fig. 2(c). Grip strength performance is greatest in the rain forest, with the grip strength being approximately equal at both sea level and at high-altitude regions of Peru. The interaction suggests that these differences between boys and girls are not consistent, with the gap between girls and boys being greater in the rain forest compared with other two regions of Peru ($P < 0.01$).

### The curl-up test

The multiplicative model relating the number of curls (*n*) recorded by the children to the body size components was found to be:

$$\text{Curls } (n) = a \cdot \text{mass}^{-0.771} \cdot \text{height}^{2.038}$$

with the mass and height exponents being $k_1 = -0.771$ (SEE = 0.060) and $k_2 = 2.038$ (SEE = 0.249), respectively, but with no significant effect due to maturation offset having controlled for differences in mass, height, sex, age, etc. The adjusted coefficient of determination, adjusted $R^2$ was 20.0% with the log-transformed error ratio being 0.479% or 61.4%, having taken antilogs. The constant "*a*" varied by sex, age, and where the children lived in Peru (sea level, rainforest area, and high altitude) and many interactions between these categorical variables ($P < 0.01$). The interaction between sex and age on the number of curls (log transformed) is plotted in Fig. 1(d). The figure illustrates that for boys the number of curls increases in the older age groups, but for girls no such trend is evident. The interaction between where the children live in Peru and sex on the number of curls (log transformed) is given in Fig. 2(d).

The body mass and height components associated with the number of curls for the above model can be rearranged and expressed as a height-to-mass ratio within a curvilinear power function as follows:

$$\text{mass}^{-0.771} \cdot \text{height}^{2.038} = \left(\text{height} \cdot \text{mass}^{-0.378}\right)^{2.038}$$

because $\text{mass}^{-0.771} = (\text{mass}^{-0.378})^{2.038}$. The 95% CI for the rearranged/rescaled mass exponent −0.378 is (−0.436 to −0.320). Note that this height-to-body mass ratio is similar to the $\text{RPI} = \text{height} \cdot \text{mass}^{-0.333}$, because the 95% CIs encompass −0.333.

### The shuttle run test

The multiplicative model relating the shuttle run speed test to the body size components and maturity offset estimate was found to be:

$$\text{Shuttle speed (m/s)} = a \cdot \text{mass}^{-0.128} \cdot \text{height}^{0.324} \cdot \exp(0.020 \cdot \text{maturity-offset})$$

with the mass and height exponents being $k_1 = -0.128$ (SEE = 0.016) and $k_2 = 0.324$ (SEE = 0.064), respectively, with a significant maturation offset parameter $b = 0.020$ (SEE = 0.007). The adjusted coefficient of determination, adjusted $R^2$ was 50.3% with the log-transformed error ratio being 0.0949% or 10.0%, having taken antilogs. The constant "*a*" varied by sex, age, and where the children lived in Peru (sea level, rainforest area, and high altitude) and all interactions between the categorical variables ($P < 0.01$). The interaction between sex and age on shuttle speed (log transformed) is plotted in Fig. 1(e). The figure illustrates that shuttle run speed appears to decline with older girls, a trend that is absent for boys. The interaction between where the children live in Peru and sex on shuttle speed (log transformed) is given in Fig. 2(e).

The body mass and height components associated with the shuttle speed for the above model can be rearranged and expressed as a height-to-mass ratio within a curvilinear power function as follows:

$$\text{mass}^{-0.128} \cdot \text{height}^{0.324} = \left(\text{height} \cdot \text{mass}^{-0.395}\right)^{0.324}$$

because $\text{mass}^{-0.128} = (\text{mass}^{-0.395})^{0.324}$. The 95% CI for the rearranged/rescaled mass exponent –0.395 is (–0.491 to –0.299). Note that this height-to-body mass ratio is similar to the $\text{RPI} = \text{height} \cdot \text{mass}^{-0.333}$, as the 95% CIs encompass –0.333.

### The sit-and-reach test

The multiplicative model relating flexibility (cm) to the body size components and maturity offset estimate was found to be:

$$\text{Flexibility}\,(\text{cm}) = a \cdot \text{height}^{-1.570} \cdot \exp(0.152 \cdot \text{maturity-offset})$$

with the height exponent being $k_2 = -1.570$ (SEE = 0.209), with a significant maturation offset parameter $b = 0.152$ (SEE = 0.017). The adjusted coefficient of determination, adjusted $R^2$ was 13.7% with the log-transformed error ratio being 0.315% or 36.9%, having taken antilogs. The constant "*a*" varied by age and where the children lived in Peru (sea level, rainforest area, and high altitude) and many interactions between the categorical variables ($P < 0.01$). Interestingly, the interaction between sex and age on flexibility (log transformed) was not significant having controlled for children's height ($P > 0.05$). The interaction is plotted in Fig. 1(f). In this case, the decline in flexibility is common to both boys and girls. The interaction between where the children live in Peru and sex on sit and reach (log transformed) is given in Fig. 2(f). The figure illustrates that girls are more flexible in the rain forest and at high-altitude regions of Peru, but at sea level boys are more flexible ($P < 0.01$).

## Discussion

The present study used an allometric modeling approach to identify optimal body size and shape (using a height-to-weight ratio) characteristics associated with motor performance in six physical tests having controlled for differences in age, sex, maturity offset, and altitude sites in Peruvian children and adolescents. In aerobic performance (12-min running test), the results confirm that an appropriate height-to-body mass ratio (known as the $\text{RPI} = \text{height/mass}^{0.333}$) is a suitable predictor of cardiorespiratory capacity development. The absence of a significant maturity offset parameter suggests that aerobic performance does not benefit from being an early mature. Boys and girls have divergent performance trajectories across age, where boys significantly outperform girls. A similar finding was presented by Sweeting (2007) and Nevill et al. (2009), where height-to-body mass ratio and the RPI were used as putative indicators for children and adolescent's adiposity. Present results confirm that boys show lower levels of adiposity and greater heights (a salient ectomorphic characteristic of their physique) driving them to better aerobic results in comparison with girls. Furthermore, the RPI has been shown to be a significant predictor in aerobic endurance tests of young Japanese athletes (Tanaka & Matsuura, 1982) and Greek schoolchildren (Nevill et al., 2009).

When considering geographical sites, boys and girls from high-altitude areas performed better than those from the rainforest (751 m) and sea-level (58 m) areas in the cardiorespiratory test. It is expected that populations residing in the Andes, in their adaptation processes, exhibit various morphological and physiological changes that are not found in the other sites (i.e., rainforest and sea level). The reduction of the oxygen supply that manifests itself at these altitudes leads to a state of chronic hypoxia. As such, the inheritance of physical traits selected in hundreds of generations to provide protection against hypoxia possibly is experienced since before birth (Frisancho, 1988; Hochachka et al., 1991). For example, groups that reside at high altitude have larger lung volumes (Frisancho et al., 1997) and increased production of red blood cells, which is a well-documented mechanism to maximize the transport capacity of oxygen at high altitude (León-Velarde et al., 2000; Beall, 2001). Also, the inhabitants at high-altitude areas have broader chests in relation to their height. The transverse and antero-posterior diameter of the chest, the chest circumference, and the sternal length breadth are larger in these populations when compared with sea level (Frisancho et al., 1973; Mueller et al., 1978). These features, among other correlates, help explain that the aerobic capacity of schoolchildren who live at high altitude is significantly greater than the rainforest area and sea level, having controlled for differences in body size, demonstrating a greater capture of oxygen in physically strenuous conditions. Similar results were found in adults (Frisancho et al., 1995). Additionally, it is important to note that Cohen's effect sizes [$(0.54 \le d \le 1.40)$ in boys and $(0.17 \le d \le 1.60)$ in girls] showed to be moderate to high in anthropometry and motor performance tasks, allowing us to detect real geographical differences given that the measurement errors are low to negligible.

The allometric models used to predict explosive power (standing long jump) and abdominal strength (curl-up) tests identified the optimal height-to-body mass ratios associated with these performance tests to be $(\text{height}\cdot\text{mass}^{-0.365})^{0.735}$ and $(\text{height}\cdot\text{mass}^{-0.378})^{2.038}$, respectively. The RPI is also a good predictor of dynamic muscle strength results (Markovic, 2007; Nevill et al., 2009). Static muscle strength (grip strength) was found to be associated with being heavier and taller, given the positive exponents of body mass and height. Sex differences in strength favoring older children seem to be observed from 13 years onward, which are partly attributable to a further development of muscle strength: increases in muscle mass, total body mass, and height (Rauch et al., 2002).

It is well known that age at PHV is the chosen marker for somatic maturation (Malina & Beunen, 1996). Using Mirwald et al. (2002) maturity offset in the allometric model, we verified that its value is positively associated with standing long jump and grip strength tests, confirming the complex interaction between growth (height and body mass) and biological maturation in optimizing adolescents' motor performance (Malina et al., 2004). However, care must be exercised when interpreting the maturity offset importance given that some 16- and 17-year-olds may have stopped growing, although we do not know this for certain, unless longitudinal information was provided which is not the case. Furthermore, as described in the Methods section, because we incorporated the maturity offset within a non-linear exponential function we were also capable of modeling increasing/decreasing rates in the way maturity offset might affect motor performance in addition to age, height, and mass. When comparing geographic areas, schoolchildren's and adolescents' grip strength and curl-ups from the rainforest area showed higher values than their peers from high altitude and sea level, with more salient differences in boys. In the standing long jump test, boys residing at sea-level areas outperformed their peers. We suspect that differences in physical activity levels and patterns (recreational, sports, and/or occupational activities) whose intensity, frequency, and duration are considerable in various house chores, among other activities, as well as a more favorable climate may help in the interpretation of strength results favoring youth from rainforest area. Teenagers residing at high altitude live in climatically severe conditions that may hinder their frequent engaging in diversified physical activities that may also be associated with strength motor performance (Pawson et al., 2001). For example, between December and April is the rainy season, and from May to August, the temperature drops dramatically. In addition, there are not many sport infrastructures that may facilitate engagement of children and youth in organized sports practice (Instituto Nacional de Estadística e Informática, 2008). On the other hand, sea-level residents live in an area with high population density, serious problems of traffic congestion, and public insecurity, which may contribute to the adoption of a more sedentary lifestyle – more spare time regularly spent in passive activities such as playing computer games or watching television and participation in low-intensity household chores (Instituto Nacional de Salud, 2005).

Body mass and height with negative and positive exponents, respectively, $(\text{height} \cdot \text{mass}^{-0.395})^{0.324}$ are associated with agility (shuttle run test), suggesting that an appropriate proportion of height/body mass (RPI) is linked with higher agile subjects (Nevill et al., 2009). Furthermore, teenagers with positive maturity offset values (earlier PHV years) benefit most in this test (Malina et al., 2004). However, when in the present analysis we controlled for body mass and height, the shuttle run performance speed favors boys with a tendency to stabilize through the ages and declines slightly after 15 years, whereas in girls the speed declines progressively throughout the ages. Pena Reyes et al. (2003) compared schoolchildren from urban and rural areas in Mexico, and scan their results with and without body size and age adjustments; the differences varied by age group and sex in the speed test. The advantage of body mass and height in children and adolescents does not necessarily translates into better performance levels as stated in the results presented. Schoolchildren residing in rainforest area outperform all others from high altitude and sea level in the agility test. We have also identified that children who live in the rainforest region have significantly higher skinfold-corrected thigh girths than children in other regions of Peru. We have also identified using allometric modeling that all children have corrected thigh girths that increase at a rate (exponent = 0.36; 95% CI from 0.35 to 0.37) significantly higher than that assumed by geometric similarity (exponent = 0.33) (data not shown) as previously identified (Nevill et al., 2004). Therefore, we might speculate that the geographical advantage of living in the rainforest is due to these children having significantly greater thigh muscle mass that will result in the observed elevated performance in the agility test. Furthermore, living in a geographic area with an all-year-round tropical climate and in proximity to the Amazon forests favors schoolchildren from an early age to diversify and maximize their motor skills associated to traditional games, unstructured play, and house chores that might enhance the development of greater muscularity, whereas children living at high altitude suffer from the permanent exposure to restrictions of severe weather; likewise, the insecurity conditions and greater population density that characterizes sea level cities may seriously restrict the possibility for greater motor practice.

Moderate-to-high effects sizes (Cohen's *d*) were found for 12-min run and the shuttle run tests in boys and girls, implying a true difference among sites. Furthermore, other possible correlates to these performance differences could be found in varying degrees of gross motor coordination, motivation to perform the tests, as well as their daily physical activity routines and sports practices (Malina et al., 2004).

It is evident that flexibility performance associated with sit-and-reach type of tests depends on limb lengths, and that the amount or degree of range of motion is specific to the articulations involved. Furthermore, because girls body mass are less than boys, having a small bone constitution seem to be designed for greater amplitude of motion, especially in the pelvic region (Alter, 2004). An evidently limited flexibility occurs gradually during the period of years where lower extremities become proportionally larger in relation to the trunk, which may have contributed to the results in our study (Malina et al., 2004). In any case, it is expected an increase in performance across age in both sexes (Freitas et al., 2002). In the present study, when scaling for size, flexibility decreases in both sexes with increasing age. Furthermore, and contrary to all motor tests, no sexual dimorphism is present. A different pattern of flexibility results was found in Mexican schoolchildren where urban boys 6–9 years were significantly more flexible than rural boys, and urban girls 10–13 years were significantly more flexible than their rural peers, whereas differences of flexibility between urban and rural girls 6–9 years and boys of 10–13 years are not significant (Pena Reyes et al., 2003). It was also found that those who have positive maturity offset values were more flexible, when controlling for height differences, which is in agreement with Nevill et al. (2009) suggestion that when comparing different groups in relation to their performance in flexibility (sit-and-reach ratio), height must be controlled for, used as a covariable, as taller people are substantially disadvantaged in the sit-and-reach test. Youth residing in rainforest area (751 m) are better sit-and-reach performers than those from the sea level and high altitude, mostly so in boys. By being taller and heavier penalizes schoolchildren residing at sea level (58 m) in contrast with children residing at high altitude (4107 m), who have a more ectomorphic physique. It is expected that the participation in a diversified range of daily physical activities allows an increase in body temperature that may be linked to increase in amplitude of motion, associated to decreases in the viscosity of the fluid and significantly improving the relaxation viscous of connective tissues (Sapega et al., 1981). Furthermore, it may also be postulated that the higher environmental temperatures may favor flexibility results of rainforest children.

Notwithstanding the relevance of the present results in terms of children and adolescents motor performance interpretation given their ideal size and geographical location, one must bear in mind that the maturity offset, as an indirect measure of somatic maturation, has never been cross-culturally validated. But this is not the sole problem of this method. However, the maturity offset did not make a major contribution to our understanding in Peruvian children and youth motor performance.

In summary, the current study has identified the key body shape associated with the four body mass-dependent physical activities (the 12-min run test, standing long jump test, curl-up test, and the shuttle run test) to be the height-to-body mass ratio, known as the RPI (height$^3$/body mass or height/body mass$^{0.333}$), similar to that observed with Greek children (Nevill et al., 2009). A positive maturity offset parameter also appears to be relevant in the activities involving strength and power (standing long jump, grip strength, shuttle run test) as well as flexibility, a finding also observed by Nevill et al. (2009). Finally, the use of allometric methods (eqn. [1]) and its subsequent simultaneous inclusion as covariates of log-transformed height and body mass (eqn. [2]) provided valid inference to analyze the differences between the schoolchildren populations having controlled for differences in body size, age, sex, maturity, and levels of altitude.

## Perspectives

The current study was able to identify the ideal body shape associated with endurance and explosive athletic tests in children and adolescents from Peru. The allometric model yielded positive height and negative mass exponents that suggests the appropriate height-to-mass ratio (body shape) was the RPI (RPI = height/mass$^{0.333}$). Equally importantly was its ability to provide new insights into why these performance tests vary systematically between different geographical regions of Peru. We established, for example, that children who live at high altitude had superior endurance performance (12-min run test) compared with children from other regions of Peru (sea level and rain forest). However, because schoolchildren residing at high-altitude areas are lighter and have superior RPIs compared with children from other regions of Peru, this difference might be due to their advantage in body size/shape. Using allometric modeling to control for differences in body size (using the empirically derived height-to-mass ratio) and other confounding variables, we were able to assess that the differences in endurance running remained significant having statistically controlled for these differences in body size. Clearly, the benefits of living at high altitude provide a valuable physiological advantage over and above being lighter and more linear in body shape.

**Key words:** Allometry, motor performance, adolescents, altitude.

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