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original article

Allometric study of functional fitness of children and adolescents in a rural area of Mozambique

Estudo alométrico da aptidão funcional de crianças e jovens rurais de Moçambique

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Abstract – Few studies in Africa have investigated the physical performance of children using the allometric method. This study evaluated the functional fitness of children and adolescents in a rural area of Mozambique using the contrast between theoretical models and empirical allometric coefficients. Height and weight were measured and functional fitness was assessed using the AAHPERD, EUROFIT and Fitnessgram tests. The allometric equation $Y=aX^b$, was used. In addition to descriptive statistics, factorial ANOVA was used to test differences of body size and functional variables between sexes and age groups. An extension of the allometric equation based on ANCOVA was used after proper logarithmic transformation of all variables of interest. Mean height and weight increased with age and were significantly associated with age and sex. Functional fitness increased with age, and mean results were higher for boys. Allometric coefficients were different from those expected according to theory, and girls had higher coefficients in almost all tests. A marked sexual dimorphism was seen in functional fitness results according to age. Empirical coefficients were different from those expected according to theory, which demonstrated the absence of the presumed geometric similarity. Girls had higher coefficients than boys in all fitness tests.

Key words: Africa; Allometry; Body size; Functional fitness.

Resumo – *Pesquisas em contextos Africanos nas quais se estuda o desempenho motor de crianças através do método alométrica são escassas. O estudo teve como objetivo averiguar a variabilidade da aptidão funcional de crianças e jovens rurais Moçambicanos por meio do contraste entre expoentes alométricos teóricos e empíricos. Foram medidas a altura e o peso, e avaliada a aptidão funcional com base em testes selecionados das baterias AAHPERD, EUROFIT e Fitnessgram. Foi considerada a equação alométrica fundamental, $Y=aX^b$. Para além das estatísticas descritivas habituais, recorreu-se à ANOVA fatorial para determinar o efeito da idade e do sexo nas variáveis somáticas e funcionais. Aplicou-se uma extensão do modelo alométrico a partir da ANCOVA após transformação logarítmica das variáveis de interesse. Os valores médios de altura e peso aumentam em função da idade, interagindo significativamente com idade e sexo. Constatou-se um efeito da idade nas provas físicas, com maiores médias dos meninos. Os coeficientes alométricos encontrados são distintos dos esperados teoricamente, sendo maiores nas meninas do que nos meninos em quase todas as provas. Pode-se concluir que existe um dimorfismo sexual nas diferenças de médias na aptidão funcional ao longo da idade. Os expoentes empíricos encontrados, em ambos os sexos, são antagônicos aos esperados teoricamente, salientando ausência do pressuposto da similaridade geométrica. Nas meninas, os expoentes alométricos são, em todas as provas, maiores do que dos meninos.*

Palavras-chave: *África; Alometria; Aptidão funcional; Tamanho corporal.*

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INTRODUCTION

The interest in body size as a potentially confounding variable in studies of functional fitness has increased in recent times[1-3]. Allometric models, which can be used to extract a dependent variable free of any dimensional effect, are superior to physiological modeling for body size differences based on simple ratios[4,5]. Allometry provides an adequate interpretation of the fitness of individuals whose measures are different because it models the effect of body size and of other covariables[1,4,5].

In Sub-Saharan Africa, there is high prevalence of a small body size, as linear growth is delayed during childhood and adolescence[6]. According to studies in the literature, two major factors affect growth: inadequate dietary intake and infectious diseases[7]. Functional fitness has been analyzed in association with reduced body size in cases of chronic protein-calorie malnutrition. Small body size and reduced muscle mass have been described as factors that determine functional fitness in undernourished children[8,9]. However, when functional fitness is analyzed in association with body height or weight, the differences between undernourished and nutritionally normal children are substantially reduced or disappear[10,11].

Studies conducted in developing countries have used allometry to evaluate functional fitness, particularly maximum oxygen consumption (VO_2max) among children and adolescents[12,13], and the effect of body size on aerobic capacity has been clearly documented. In contrast, living in an urban or rural area in these countries does not seem to affect the physical performance of children and adolescents according to allometric studies[14].

Few studies have evaluated the functional fitness of African children and adolescents using allometric models. To our knowledge, the only studies to focus on this issue and include African children and adolescents were those conducted by Corlett[15,16]. That author investigated the effect of size variables on the fitness of Botswana boys and girls aged 7 to 12 years and found differences between the values described in theory and the empirical size coefficients, a finding that was explained by the lack of substantial variation in body composition[15]. When handgrip was compared considering area of residence, urban children performed better than rural children of both sexes, even after adjustments were made to account for size differences[16]. These studies included only pre-puberty individuals, and only a small number of similar studies were conducted in Africa, which stresses the need to conduct further investigations in this area.

Mozambique is a country with marked socioeconomic differences and environmental conflicts between the urban and the rural areas, which favors the presence of individuals with different body sizes in the countryside and the cities. As far as we know, no studies have evaluated the functional fitness of children and adolescents in this country using allometry. This study evaluated the variability of functional fitness coefficients of children and adolescents in a rural area of Mozambique by comparing values described in theory and empirical allometric coefficients.

METHODS

Sample

This study included 840 children and adolescents of both sexes (456 boys and 384 girls) aged 7 to 16 years. All participants lived in Calanga, a rural town 75 km north of Maputo, the capital of Mozambique, and that has a surface of 2,373 km^2 and a population of 9,451 inhabitants, 3,361 of whom are children and adolescents aged 6 to 20 years[17]. All participants were students in primary and secondary schools of the National Education System and accounted for 23.62% of the Calanga population aged 6 to 20 years.

The study methods and objectives were previously explained to parents and education officials, as well as to school representatives and community leaders. Parents and school representatives were asked to read and sign and informed consent term with details about the study objectives and main procedures. Parents or guardians of all participants signed this term to participate in this study, which was approved by National Health and Education Authorities in Mozambique and by the National Bioethics in Health Committee.

Anthropometry

Weight and height were measured using a stadiometer (Harpender®, Holtain. Crymych, United Kingdom) and a scale (Secca®, M 01-22-07-245. Secca, Germany) following the standards described by Lohman et al.[18].

Functional fitness

Functional fitness was evaluated using the following tests: 1) AAHPERD[19]: 1-mile run; 2) EUROFIT[20]: standing long jump, bent arm hang test, 10 x 5 meter shuttle run and handgrip test; and 3) Fitnessgram[21]: curl-up test. Except for the 1-mile run, curl-up test, bent arm hang test and shuttle run, each individual was allowed two repetitions of all fitness tests. In this case, the best result was recorded. To minimize error variance in both anthropometric measurements and physical fitness tests, participants were evaluated by the same observer.

Allometric procedures

Fitness was analyzed according to the expected theoretical association with height, the dimensional variable most often used[22]. The expected allometric coefficients (*b*) were those defined by Astrand & Rodahl[23] for the standing long jump, handgrip test and shuttle run, by Jaric et al.[24] for the curl-up test and bent arm hang test and by Rowland[25] for the 1-mile run: horizontal long jump, b=1; handgrip, b=2; shuttle run, b=0; curl-up and bent arm hang tests, b=-0.33; and 1-mile run, boys b=-1.60 and girls b=-1.17.

We used a well-known power function, $Y = aX^b$, which may be easily linearized by log transformation of each term of the equation, so that Log Y = log a + b log X. The most relevant parameter in this equation is b, interpreted as the allometric coefficient, or phenotypic regression coefficient.

Statistical analyses

Standard descriptive statistics were used (mean and standard deviation), as well as the Kolmogorov-Smirnov test, to confirm the normal distribution of data. Two-way analysis of variance (ANOVA) was used to calculate the effect of age and sex on body size and functional variables. An extension of the general allometric model suggested by Nevill et al.[1] for analysis of covariance (ANCOVA) was applied to examine size effect on fitness tests. Before that analysis, the variables for body size and functional fitness were log transformed. The SPSS 14.0 was used for all statistical analyses, and the level of significance was set at 0.05.

RESULTS

Descriptive results of height, weight and factorial ANOVA values for the comparison of means between sexes according to age are shown in Table 1. As expected, mean height and weight increased with age, and there was a significant interaction between age and sex. However, the effect of sex was evident only on weight.

Table 1. Descriptive values of height and weight according to sex and age (mean ± standard deviation) and 2-way ANOVA values resulting from the comparison of mean values between sexes according to age.

	Height (cm)		Weight (kg)	
Age (years)	Boys	Girls	Boys	Girls
6-7	113.8±1.1	112.8±1.2	19.6±0.6	19.4±0.7
8	120.4±1.1	120.4±1.2	21.8±0.7	21.4±0.7
9	125.2±1.3	125.4±1.5	24.1±0.8	24.0±0.9
10	128.1±1.3	128.6±1.4	25.6±0.8	25.9±0.8
11	134.3±1,4	134.4±1.2	27.7±0.9	28.9±0.7
12	137.7±1.4	139.2±1.4	30.6±0.8	32.8±0.9
13	143.3±1.1	147.4±1.3	35.0±0.7	38.9±0.7
14	146.8±1.2	151.2±1.2	37.6±0.7	40.3±0.7
15	153.6±1.3	150.9±1.5	40.9±0.8	42.0±0.9
≥ 16	161.5±1.1	159.2±1.7	47.6±0.7	47.7±1.0
Values ANOVA	Age effect: $F = 275.15; p < 0.001$ Sex effect: $F = 0.083; p < 0.774$ Interaction: $F = 2.35; p < 0.013$		Age effect: $F = 292.68; p < 0.001$ Sex effect: $F = 9.52; p < 0.002$ Interaction: $F = 1.97; p < 0.040$	

Table 2 shows mean values and ANOVA results of the different functional fitness tests according to sex for different ages. Age had a clear effect on all physical fitness tests, demonstrated by the increase of mean values as age advances. Boys had higher mean values in all tests at almost all ages.

Table 2. Descriptive values (mean ± standard deviation) for boys and girls in rural areas of Calanga in the different functional fitness tests and results of comparison (1-way ANOVA) of means between sexes according to age.

Age (years)	Horizontal long jump (cm)		Bent arm hang test (s)		Curl-up test (repetitions)		Handgrip test (kg)		Shuttle run (s)		1-mile run (s)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
6-7	106.2±3.6	99.1±3.6	6.6±1.3	7.7±1.4	1.6±1.2	1.4±1.2	9.3±0.8	7.1±0.8	27.8±0.5	27.9±0.4	549.9 ±14.0	611.7±13.4
8	117.7±3.7	119.5±3.8	4.8±1.4	7.9±1.5	3.3 ±1.2	2.8±1.1	10.8±0.8	9.4±0.8	26.2±0.5	27.0±0.4	512.1±14.5	567.8±13.8
9	129.8±4.2	124.8±4.8	9.4±1.6	8.3±1.8	4.5±1.3	6.6±1.4	12.9±0.9	10.8±1.0	25.2±0.6	25.9±0.6	525.1±16.3	528.7±16.6
10	131.6±4.1	135.5±4.9	11.1±1.6	11.6±1.9	4.8±1.3	6.0±1.4	14.8±0.9	12.1±1.0	24.6±0.5	26.0±0.5	512.2±14.7	524.9±16.3
11	133.6±5.0	129.6±3.9	10.9±1.7	8.3±1.5	3.3±1.5	8.0±1.2	16.5±1.0	14.9±0.8	23.5±0.6	23.8±0.5	507.2±16.3	542.4±13.4
12	144.2±4.4	142.6±4.5	14.4±1.8	11.6±1.7	8.7±1.4	4.8±1.4	18.6±1.0	18.2±1.0	23.4±0.5	23.6±0.6	502.3±15.3	537.5±15.9
13	150.3±3.6	147.6±3.9	11.2±1.3	7.9±1.5	8.8±1.1	5.8±1.3	21.5±0.9	20.4±0.9	22.6±0.5	23.0 ±0.5	482.5±12.8	577.4±13.4
14	160.5±3.9	149.6±3.8	16.1±1.4	9.6±1.4	11.9±1.2	6.9±1.2	24.8±0.8	24.5±0.8	22.7±0.5	23.1±0.5	479.6±14.7	543.2±13.0
15	165.7±4.1	147.9±4.7	14.6±1.6	7.5±2.0	10.5±1.3	7.4±1.6	27.6±0.9	26.2±1.0	22.1±0.5	24.1±0.6	446.9±17.0	551.9±16.6
≥ 16	177.1±3.3	147.1±6.5	17.9±1.3	8.5±2.5	14.7±1.0	8.0±2.0	34.7±0.7	29.3±1.3	22.0±0.4	22.8±0.9	423.9±13.8	563.7±22.5
Values 2-way ANOVA	Age effect: F = 44.44; p < 0.001 Sex effect: F = 14.89; p < 0.001 Interaction: F = 2.33; p < 0.014		Age effect: F = 4.92; p < 0.001 Sex effect: F = 14.94; p < 0.001 Interaction: F = 2.96; p < 0.002		Age effect: F = 10.63; p < 0.001 Sex effect: F = 5.70; p < 0.017 Interaction: F = 3.26; p < 0.001		Age effect: F = 146.32; p < 0.001 Sex effect: F = 21.51; p < 0.001 Interaction: F = 1.10; p < 0.361		Age effect: F = 28.30; p < 0.001 Sex effect: F = 9.89; p < 0.002 Interaction: F = 0.668; p < 0.739		Age effect: F = 5.33; p < 0.001 Sex effect: F = 78.08; p < 0.001 Interaction: F = 3.28; p < 0.001	

Table 3. Values of *b* coefficients in the different functional fitness tests according to analysis of power function

Functional fitness tests	Allometric coefficients			
	Theoretical		Empirical	
	Scale factor: Height			
	Boys	Girls	Boys	Girls
Horizontal long jump	1	1	0.85	1.21
Bent arm hang test	-0.33	-0.33	-0.48	0.49
Curl-up test	-0.33	-0.33	0.44	2.67
Handgrip test	2	2	1.86	3.0
Shuttle run	0	0	-0.13	-0.44
1-mile run	-1.60	-1.17	-0.42	-0.25

The interaction between age and sex was significant in most tests, except in handgrip and shuttle run.

Table 3 shows all empirical coefficients, which were different from those expected according to theory. In the bent arm hang test, the allometric sign was opposite for boys and girls. In the curl-up test, the difference was much higher than the theoretical value and very different between boys ($b = 0.44$) and girls ($b = 2.67$). The same pattern seems to be found for the handgrip test. There is a clear difference between the theory value ($b = 0$) and the results of the shuttle run (boys, $b = -0.13$; girls, $b = -0.44$). In the 1-mile run, the allometric values for both sexes (boys, $b = -0.42$ and girls, $b = -0.25$) were greater than the coefficients found in the theory (boys, $b = -1.60$ and girls, $b = -1.17$).

DISCUSSION

The main objective of this study was to evaluate the variability of functional fitness among children and adolescents in a rural area of Mozambique by comparing values found in the theory and empirical allometric coefficients. Therefore, our results of descriptive analyses and analysis of variance of body size and functional fitness will be briefly discussed for illustrative purposes only.

Mean height and weight of children and adolescents in our sample were lower than the normative values described by the CDC/NCHS/WHO[26], as previously reported for Mozambican schoolchildren in Maputo[27]. The lower height and weight of Africans in comparison with European and American children and adolescents should be assigned to environmental conditions, such as poor sanitation, nutritional deficiencies and lack of primary healthcare services[27].

In contrast, as expected, mean physical fitness values increased with age, results that are similar to those reported in previous studies with Mozambican schoolchildren and adolescents in Maputo[27,28], as well as with Botswana children[15].

Analysis of variance demonstrated a difference in the pattern of behavior of means between sexes according to age: there was a predominance of elevated means among boys in all tests and in most age groups. Girls had a stable or declining performance in most tests starting at age 13 years. These results confirm those found in other studies conducted in urban areas of Mozambique[27,28].

Other studies with children and adolescents in Maputo found an advantage of individuals in lower socioeconomic classes in several fitness tests[28]. Their superior performance was explained by the fact that children and adolescents that grew up under unfavorable conditions had to engage in daily household chores that required physical activities of considerable duration, frequency and intensity. In the actual case of our sample, a rural population for whom family subsistence chores are unavoidable for their daily survival, the life style demanded by such engagement seemed to have particular reflexes on their level of functional fitness.

Several studies in the literature provide enough evidence of the usefulness of analyzing scale effects based on the assumption that geometrical similarity might explain the association of several factors with body size effects in several physical performance tests[1,4,6]. However, similar investigations in Africa are practically nonexistent, which limits the interpretation of our results.

The phenotypic regression coefficients found in our study are different from those assumed by the theory of geometrical similarity. This finding seems to suggest that, in the actual case of children and adolescents in our sample, the values in the theory did not describe the association between body size and functional fitness. In fact, while boys had lower empirical allometric coefficients in most tests, the girls had higher empirical coefficients in all tests, except in the shuttle run.

Empirical coefficients higher than those assumed in the geometric similarity theory were also found by Corlett[15,16] among Botswana boys and girls, and the higher values were also found for girls. For that author, the higher allometric coefficients in African children may be assigned to the fact that allometric models are based on assumptions that do not take into consideration several maturational factors. At the same time, those models assume that body shape and composition are constant during growth, which does not seem to be the case for the growth of children and adolescents in Africa.

Among boys, our allometric coefficients showed that, except for the 1-mile run and curl-up test, which were higher than expected, the increase in functional fitness with age and assigned to body size gains was substantially lower than expected. In contrast, the higher coefficients found among girls in all performance tests, except the bent arm hang test, indicate a greater improvement of performance due to gains in body size. This association between functional fitness gains as a function of increases in body size during growth, as well as the differences in its patterns according to sex, seems to be affected by a strong environmental factor in our sample. In fact, a recent study with the same population[29] found that the prevalence among boys and girls was 24.2% and 21.3% for the stunted category, 11.4% and 7.0% for the wasted group, and 7.1% and 4.2% for the simultaneously stunted and wasted individuals. Also, mean height and weight values were below the 25th percentile of the norms described by the CDC/NCHS/WHO[26]. In contrast, the pattern of prevalence according to sex revealed a greater frequency among boys than girls, which seems to partially explain the predominance of higher empirical coefficients in that groups. Our results clearly reflected a negative effect of nutritional breakouts under which these children were developing, and their hindering effects on the expression of the genetic potential of body size and on their physical performance.

The differences between the allometric coefficients found in our sample seem to implicitly confirm the presence of a difference in the growth dynamics between sexes. In contrast, the significant interactions between sex and age for body size seem to ass to this fact. The girls had higher empirical coefficients in the fitness tests, which suggests that other factors, in addition to the simple increase in body size, may determine the level of performance in these tests. In turn, boys, who had lower empirical coefficients in almost all tests, clearly demonstrated a delay in physical performance gains during growth as a function of body size gains.

This discussion should take into consideration that the values defined in the geometrical similarity theory are specific only for each test, and not for each individual. Moreover, the term "allometric" is based on the assumption that the empirical parameter does not necessarily have to be the same as the one defined in theory[30]. Therefore, an integrated approach to this issue in rural areas may help to understand the usefulness of allometric analyses to compare functional variables in and between groups that live in a specific context.

CONCLUSIONS

The results of this study suggest that: (i) empirical coefficients were different from the expected values according to theory, which demonstrated the absence of the presumed geometric similarity. (ii) sex dimorphism was evident in the pattern of physical performance improvement during growth as a result of body size gains, and the girls had phenotypic regression coefficients predominantly greater than the values expected according to theory in all functional fitness tests when compared with boys.

Although empirical coefficients were higher for girls in most functional tests, boys had higher mean values of functional fitness in all tests, which suggests that there are other factors, and not only body size gains, that affect the levels of functional fitness in this sample of a rural population. Such factors are likely to be associated with the demands of daily subsistence chores and the richness of the games played among children in the rural area where our study participants lived.

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