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THE INFLUENCE OF THE ALLOMETRIC SCALE ON THE RELATIONSHIP BETWEEN RUNNING ECONOMY AND BIOMECHANICAL VARIABLES IN DISTANCE RUNNERS

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Abstract. Studies have demonstrated the need for the use of parameters that diminish the effect of body mass, for intra and inter group comparison, in individuals with different masses in order to provide a different analysis on the behaviour of the relation between running economy (RE) and biomechanical variables (BVs). The allometric scale is represented by a regression equation that indicates the behaviour of a physiological variable in relation to the variable mass ($RE=a.x^b$), where x is body mass in (kg) and the dimensionless coefficient a is characteristic of the species analysed, and the dimensionless exponent b determines the percentage of mass to be associated with the physiological variable. The influence of the allometric scale (b=-1; -0.75; -0.73; -0.67) on the relationship between RE and BVs - stride length (SL), relative stride length (RSL), stride rate (SR), stride time (ST), support time (SUPT) and balance time (BALT) - at 12 $km \cdot h^{-1}$, was analysed in nine elite runners. Factorial analysis and Pearson's Correlation Coefficient test (r) with P<0.05 were used. A decrease in the explanation power of the RE was observed, with the use of the allometric exponent, due to the BVs, as well as a reduction of the correlation coefficients between SL versus RE, ST versus RE and SR versus RE. The BALT presented a higher correlation where b=-0.75. The RSL and SUPT presented non-significant correlations. The variables SL, ST, SR and BALT were the most effective predictors of the RE, Where: b=-1, the allometric scale was most efficient to predict the running performance.

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Key words: Running economy - Allometric scale - Biomechanical variables

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Introduction

An organism with a greater mass presents a higher metabolic rate than an organism with a smaller body mass, as there is an increasing proportional relationship between mass and metabolism [8]. It may, however, present smaller physiological values than the smaller organism, where the values of this variable are normalized based on the body mass values [11,15]. In the first case, the metabolic rate will be expressed in an absolute form, by means of a unit that represents the total quantity of the variable for each kilogram of body mass ($^{-1}$).

The oxygen uptake divided by the total mass of the individual may yield a result that contrasts with other data, because it leads to the assumption that heavier athletes with lower relative submaximal oxygen uptake ($VO_{2submax}$) are more economical at a given velocity, as they need to consume less energy. Accordingly, the need to carry out comparisons of physiological variables between organisms belonging to the same group, or between different groups, may lead us to diverse assertions based on results that can be altered according to the manner by which the body mass of these organisms is associated with the physiological variables to be analysed [3].

Brisswalter [3], West [22] and Darveau [6] point out the need to use parameters that lessen the effect of body mass when comparing intra and inter groups with individuals of different body masses, in order to permit a different analysis of the phenomenon. An example of this is the allometric scale. It is represented by means of a regression equation that indicates the behaviour of a physiological variable *y* in relation to the variable mass x ($y=a.x^b$), where coefficient *a* is characteristic of the class analysed and the b (allometric exponent) determines the percentage of mass to be associated with variable y.

A few studies have focussed on determining the exponent that best represents the percentage of body mass required for carrying out comparisons of the *y* variable by minimizing the effect of the difference in mass. To this end, such research projects have made use of studies related to the metabolic assessment of different animal species [6,24]. The work of Rubner apud White and Seymour [23], dated from the late XIX century, claimed an association of metabolic rate with 2/3 of the individual's body mass (0.67). Svedenhag and Sjödin [20] found allometric exponents between 0.73 and 0.75 in distance runners and marathon runners, demonstrating an influence of the allometric scale on $VO_{2submax}$.

In the practice of sports, other studies have equally verified the need for utilizing different values, such as coefficients, for determining the percentage of total body mass to be considered. These values would be specific for different sports [11], as well as for wheelchair users [9]. Therefore, the purpose of this study was to analyze the influence of the allometric scale on the relationship between running economy (RE) and biomechanical variables (BVs), at submaximal running intensity.

Materials and Methods

Nine female elite runners, (5 distance runners and 4 long distance runners), with more than 5 years professional experience, from the Porto Alegre Gymnastics Society, were voluntarily recruited. All have attended the Exercise Research Laboratory of the Federal University of Rio Grande do Sul (Brazil) in order to complete the forms with their personal details and informed consent term, which is in accordance with the recommendations of the American College of Sports Medicine (ACSM), proposed in 1991 [1].

Firstly, the maximal oxygen uptake test (VO_{2max}) (Test 1) was carried out in order to characterize the sample. The RE test (Test 2) was carried out with a minimum two-day interval. The ambient temperature oscillated between 22°C-24°C.

For both tests all the subjects were instructed to wear the same type of training shoe (rubberized footwear without spikes,) and all had experience in treadmill running.

The subjects were instructed to fast two hours prior to each testing session. There was no intake of any kind of energetic substance during the tests.

Test 1: Maximal oxygen uptake (VO_{2max}) determination test: The subjects were recommended to perform a brief stretching session and, after having been fitted with a heart rate monitor (HRM) and a gas-collecting mask, they remained seated for roughly three minutes prior to the start of the test.

In this experiment, a progressive workload test, using ramp mode, was carried out on a treadmill. The initial workload (velocity) was 9 $km \cdot h^{-1}$, with an increment of 0.5 $km \cdot h^{-1}$ every 30 seconds. The workload increments were sufficient for test duration of 8-14 minutes. The ramp mode facilitates the visualization of the ventilatory thresholds (VT) and, in addition it is effective for determining VO_{2max}.

The criteria utilized to determine the VO_{2max} were the same adopted by His [10], which consists of the observation of, at least, two of the following criteria:

- voluntary selection of the subjects;
- plateau of the oxygen uptake curve (VO_2);
- respiratory exchange ratio higher than 1,15

During the tests, the subjects did, at any time support themselves on the treadmill for support.

Test 2: Running Economy (RE) determination test: The RE has been defined as the steady state of $VO_{2submax}$ for a velocity [5]. In order to determine the RE, an adaptation of the protocol proposed by [19] was carried out, which consists of a stage of the 7 minutes. In the present study, this was changed to 6 minutes due to the possibility of the stabilization of VO_2 at three minutes, allowing for a $VO_{2submax}$ plateau in providing the RE information [2]. The $VO_{2submax}$ was determined from the mean values that were found between 5 to 6 minutes. The total duration of the test was 6 minutes for each individual. The respiratory switch ratio did not exceed 0.95.

Firstly, the subjects performed a warm-up session consisting of stretching and run at 9 $km \cdot h^{-1}$, for 3 minutes. Then, the subjects performed a submaximal 6 minutes at 12 $km \cdot h^{-1}$ (85% of VO_{2max}). This velocity was chosen for three reasons: 1) at 12 $km \cdot h^{-1}$ the subjects presented RE values situated at an intermediary zone between the first and the second ventilatory threshold, which is ideal for the analysis of the running economy [19]; 2) McMiken and Daniels [17] showed that there is no significant difference between the aerobic requirement in treadmill running, above 73% of VO_{2max} and ground running; and 3) 12 $km \cdot h^{-1}$ corresponds to a velocity adopted by the literature for RE analysis [13,18,19].

During the economy test, the individual's left sagital plane was videotaped using a Pulnix F4 video camera with a sampling rate of 120 frames per second and a shutter velocity of 11000^{-1} per seconds, where three gait cycles were recorded. The camera was positioned three meters from the subject to be assessed and one meter above ground-level.

Once the RE and BVs values had been determined, an analysis of the influence of the allometric scale (b=-1; -0.75; -0.73; -067) on the relationship between the RE and the BVs – stride length (SL), stride length relative to the length of the left lower limb (RSL), stride rate (ST), support time (SUPT) and balance time (BALT)- was carried out. The distance between the lateral malleolus of the fibula and the femoral greater trochanter was considered the length of the left lower limb [21]. The following mathematical formula was applied in order to acquire the RE values with the allometric exponents under consideration.

$$RE = a.x^{b}.1000$$

where:
RE: running economy values with allometric exponent (b)
a: $VO_{2submáx}$ ($ml \cdot min^{-1}$)
x: body mass (kg)

The SL was determined from the classical running formula (v = SL x SR), by dividing the horizontal velocity by the stride rate. The ST was determined through the summing up of the frames from a complete stride cycle and then multiplied by 8.33×10^{-3} (estimated frame time). The SUPT and BALT were determined by means of the visual analysis of the beginning and completion of the support phase through visual analysis of the spatial model.

Statistical analysis: All the variables (RE and BVs) were tested in relation to their normality, that is, the similarity of their distributions in relation to the Gaussian distribution, by means of a Shapiro-Wilk test. The homogeneity of the variance was assessed using Levene's test. The results showed significance indices higher than 0.05, indicating normal distribution, allowing for the use of parametric statistical tests [18].

Descriptive statistics were carried out through the mean and standard deviations.

In an effort to reduce the number of variables in dimensions in order to better explain the variability of the phenomenon under consideration, factorial analysis of the main components was performed on the different percentages of body mass. The main components are formed through the relationships between the variables. The cut-off value for the extraction of the component for each factor was 0.50. Pearson's Correlation Coefficient test (r), with $P<0.05$, was applied to verify the existence of an association between the variables RE versus BVs, in the different body mass percentages.

Results

The physical and physiological characteristics are presented in Table 1.

Table 1
Physical characteristics of the subjects; values are means and SEM

Variables n=9	c	d	SEM	95% of confidence interval of the median		Min	Max
				Lower Limit	Upper Limit		
Age (years)	26.00	±14.58	4.86198	14.78824	37.2117	13.00	50.00
Height (cm)	160.83	±6.18	0.02062	156.0789	165.5877	153.00	171.00
Weight(kg)	50.16	±7.96	2.65288	44.0491	56.2842	33.40	59.20
VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.14	±4.08	1.35914	40.0103	46.2786	36.70	51.00

The results of the factorial analysis of the main components are shown in Table 2.

Table 2
Explanation of the variance of biomechanical variables using the allometric scale

			Proper values		Extraction of sums of frames		
Allometric scale	Factor	Total	% of variance	% accumulated	Total	% of variance	% accumulated
-1	1	5.303	75.759	75.759	5.303	75.759	75.759
-0.75	1	5.244	74.916	74.916	5.244	74.916	74.916
-0.73	1	5.219	74.566	74.564	5.219	74.564	74.564
-0.67	1	5.159	73.695	73.695	5.159	73.695	73.695

By analysing the results in Table 2, a decrease can be observed in the explanation power of the variability of the BVs by means of the allometric scale, through exponential values (b=-1; -0.75; -0.73; -0.67). These results demonstrate that, in the group under analysis, the allometric scale was more effective in predicting the running performance where b=-1.

In Table 3, decreases in the correlation coefficients between SL vs $VO_{2submax}$; ST vs $VO_{2submax}$, and SR vs $VO_{2submax}$ with the use of the allometric scale. Where b=-0.75, BALT showed a higher correlation coefficient. The SL and SUPT showed insignificant correlations. Of the four exponential values under analysis in this study, $VO_{2submax}$, where relativized at kg^{-067}, showed a lower influence on the relationship between RE vs BVs.

Table 3
Correlation coefficients between $VO_{2submax}$ vs BVs using the allometric scale

Allometric scale	Biomechanical variables					
	SL	ST	SR	BALT	RSL	SUPT
-1	-0.829*	-0.829*	0.790*	-0.697*	-0.438	-0.386
-0.75	-0.720*	-0.718*	0.707*	-0.814*	-0.617	0.119
-0.73	-0.699*	-0.698*	0.687*	-0.803*	-0.613	0.144
-0.67	-0.643	-0.640	0.636*	-0.777*	-0.608	0.214

Note: SL - stride length; ST - stride time; SR - stride rate; BALT - balance time; RSL - relative stride length; SUPT - support time; *P<0.05.

Discussion

Many authors have studied the influence of the allometric scale on the relationship between oxygen uptake and physical activity. Jensen *et al.* [11], analysing the VO_{2max} of the 967 athletes, representing 25 different sports, found different values for the allometric exponents (b) for each type of sport, with emphasis on the value b=0.73 for distance running and cycling types, which demonstrates that the allometric scale can be useful in understanding the variability of the maximal aerobic capacity and the physiological limitations of the working capacity.

In relation to the $VO_{2submax}$, Svedenhag and Sjödin [20] found allometric exponents between 0.73 and 0.75 at long distance runners, which demonstrates that the allometric scale can be applied to submaximal running intensities. Additionally, by analysing the allometric results from seven males and nine female cross-country athletes, resulting from the relationship between the peak oxygen uptake (VO_{2peak}) and body mass, Larsson *et al.* [14] found allometric exponents corresponding to 1 and 0.67, which demonstrates that gender may interfere with the relationship in question and, consequently, with the overall performance of such athletes.

The divergences found in the studies from Svedenhag and Sjödin [20], Jensen *et al.* [11] and Larsson *et al.* [14] demonstrate that allometry may yield different results, according to the type of sport analysed, the effort intensity exerted, gender and individual physical fitness. Moreover, they demonstrate that, as yet, there is no consensus in the literature concerning the use of the allometric scale, the exponential value to be utilized in a given situation, and particularly, regarding the causes leading to the utilization, or not, of a given allometric exponent.

In the biological field, the works by Rubner apud White and Saymour [23], dated from the late XIX century, claimed an association of the metabolic rate with 2/3 of the individual's body mass (0.67). In 1932, Kleiber [12] raised the need for the exponent to be used to have a value higher than the one suggested by Rubner. Brody [4], corroborating the findings in Kleiber's studies, determines this exponent as being relative to ¾ (0.75) of the body mass. In 1997, West and associates [22] observed that the exponent ¾ could additionally be used in the comparison of vascular systems between diverse animal, microorganism and plant species. In 2002, Darveau and associates [6] advocated the need to use different exponents, specific for each physiological condition of the individual.

Allometric conditions have also been used by nutritionists in estimating calorie needs; by archaeologists, in estimating the body weight from the dimensions of bones found by anthropometrists, for determining body proportions; and by physicians for estimating medication doses. While all the estimates derived from allometric equations may not necessarily be exact, they do permit an approximation that makes it possible to predict the variation that can be attributed to the body size [7].

Unlike the allometric values observed in previous studies, Brisswalter *et al.* [3], when analysing the influence of the allometric scale on the relationship between RE and the anthropometric measurements (body weight, fat percentage, height and leg length) from 28 (half-marathon runners), at two submaximal running intensities (9 and 12 $km \cdot h^{-1}$), corresponding to an intensity below the anaerobic threshold, and the second very close to the threshold, found higher correlation when the athletes were running at 15 $km \cdot h^{-1}$, regardless of the allometric coefficient used (b=1 and 0.75). The authors justify these outcomes in view of the speed of the trial, 9 $km \cdot h^{-1}$, which corresponds to a very low competition speed which, in turn, corresponds to a biomechanical discomfort. In contrast, 15 $km \cdot h^{-1}$ corresponds, precisely, to the competition speed of these athletes, at which greater physiological and biomechanical adaptation is achieved. Moreover, Brisswalter *et al.* [3] found that, at 15 $km \cdot h^{-1}$ and where b=1, there was a greater influence of the allometric scale on the relationship between the RE and the anthropometric variables, especially related to body mass, height/stature and lower limb length. The authors believe that this outcome may be related to the fact that significant reverse correlations occurred between $VO_{2submax}$ and the anthropometric variables. By relativizing VO_2 values with 100% of the body mass (b=1), a greater heterogeneity is yielded in RE values and, consequently, there is a greater chance of occurring greater correlations between $VO_{2submax}$ and anthropometric variables.

While the authors do not demonstrate results referring to the absolute value of VO_2, it is believed that these results might be very similar among the subjects under analysis.

In this study, we found that, irrespective of the statistical analysis adopted (factorial analysis of the main components and/or linear correlation analysis), the influence on the relationship between the RE and BVs of the allometric exponent b corresponding to '1', was higher than the other allometric exponents that were used in this study, which corroborates the findings in the studies by Brisswalter *et al.* [3]. We believe that this outcome might be related to the heterogeneity of the anthropometric values (body weight and height) and, principally, the heterogeneous values of $VO_{2submax}$ found at the submaximal running intensity adopted in this study (12 $km \cdot h^{-1}$). Additionally, it was observed that, where b=0.67, two of the six correlations were not significant, demonstrating that the influence of body weight, as well as the overall anthropometric analysis of the analysed subjects, is important in the relationship between the RE and the BVs, since this relationship directly impacts the RE values.

The biomechanical variables that were most related to the RE were SL, ST, SR and BALT. Cavanagh and Kram [5], and Tartaruga *et al.* [21], found that stride length, stride rate and stride time were the biomechanical variables that most related to the RE.

Finally, Martin *et al.* [16] highlighted three issues that should be considered in choosing the allometric scale in studies with humans, so that the findings can be replicated more effectively: 1) taking into consideration the statistical measures and outliers when choosing of the allometric exponent; 2) recognition of the percentage of influence of the intervenient variables (e.g., anthropometric, psychological variables interfering with the outcomes of VO_2; 3) caution in the inference of the results obtained through the correlation analysis. According to the authors of this study, any of these issues can interfere with the allometric results obtained for a given group and, consequently, the chance of replication of these results is likely to be diminished.

Conclusion

The relationship between RE and BVs, in the group under analysis, was greater where the $VO_{2submax}$ values were relativized at 100% of the body mass, that is, where b=1 the allometric scale was more effective in predicting the running performance. However, anthropometric measures, statistical analyses, as well as the type of sport under analysis, exertion intensity, gender and the individual physical fitness, can impact on the determination of allometric coefficient values to be used in each study. It is suggested that further studies on the subject be undertaken.

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