APPLICATION OF THE ALLOMETRIC SCALE FOR THE SUBMAXIMAL OXYGEN UPTAKE IN RUNNERS AND ROWERS

Accepted for publication 13.07.2010

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ABSTRACT: Background: The aim of the current study was to determine the allometric exponents for runners and rower's metabolic cost, while also verifying the relation of performance with and without the allometric application. Methods: Eleven runners (age: 22.3±10.4 years; height: 174±8.8 cm; body mass: 61.7±9.3 kg; maximum oxygen uptake ($\dot{V}O_2max$): 56.3±3.9 ml·kg^{-1}·min^{-1}) and fifteen rowers (age: 24±5.4 years; height: 185.5±6.5 cm; body mass: 83.5±7.2 kg; $\dot{V}O_2max$: 61.2±3.4 ml·kg^{-1}·min^{-1}) carried out a specific progressive maximum test. The allometric exponent was determined from the logarithmic equation *Log y = Log + b Log x*, where *x* is the mass, *y* is the VO_{2max} (l·min^{-1}), *a* is one constant and *b* is the allometric exponent. The data were analyzed using descriptive and comparative statistics (independent T test of the Student), with $p<0.05$ (SPSS version 13.0). Results: The allometric exponent of the rowers was 0.70 and that of the runners was 1.00. Significant differences were found between the fat mass percentage, with higher value for rowers, suggesting that this variable may influence the behavior of the allometric exponent and consequently of the basal metabolic rate. Conclusions: Scaling may help in understanding variation in aerobic power and in defining the physiological limitations of work capacity.

KEY WORDS: biomechanics, physiology, exercise physiology, running, rowing

INTRODUCTION

An organism with a larger body mass has a higher metabolic rate than an organism with a smaller body mass because there is a proportional relationship between mass and metabolism [7]. However, larger organisms may present lower physiological values than smaller organisms when the values of this variable are normalized by body mass values [11,13]. In the first case, the metabolic rate is expressed in absolute terms by a unit that represents the total amount of the evaluated variable. In the second case, it is expressed in relative terms by a unit that represents the amount of the evaluated variable for each kilogram of body mass.

The maximum oxygen uptake ($\dot{V}O_2max$) is considered the main measure for evaluating cardiorespiratory conditioning. It can be expressed in absolute terms (l·min^{-1}) or relative to the body weight (ml·kg^{-1}·min^{-1}) [14]. The relative values are used to make comparisons between subjects that differ in terms of body mass and lean body mass, height and percentage of fat, since the muscle involved in the activity influences these values [6]. However, in high performance sports, the submaximal oxygen uptake $\dot{V}O_2submax$), that is the economy of movement, has been shown to be better parameter when assessing performance. The $\dot{V}O_2submax$ or economy running, defined as the oxygen uptake at a determined submaximal intensity of movement, can be responsible for up to 30% of the performance in long distance runners [4].

Brisswalter *et al.* [2], West *et al.* [18] and Darveau *et al.* [5] point out the need to use parameters that allow comparison of physiological variables, such as the $\dot{V}O_2max$, between individuals with different masses. An example is the allometric scale [11,13,19]. It is represented by means of an equation that indicates the behaviour of a physiological variable *Y* in relation to the variable mass *X* ($Y = aX^b$), where *a* is the allometric coefficient (a constant that is characteristic for the organism) and *b* is the allometric or scaling exponent. This exponential function can be transformed into a linear function: $Log\ y = Log\ a + b\ Log\ x$.

In relation to the practice of sports, studies have reported the need to use different values, such as allometric coefficients, in order to determine the percentage of total body mass to be considered. These values would be specific for different sports [11], as well as for wheelchair users [8]. Regarding this, Saltin and Astrand [15] affirm that the relationship between $\dot{V}O_2max$ and body mass is used because there are many types of locomotion and each one requires a body mass to be moved.

In their analysis of the relationship between $\dot{V}O_2max$ and body mass in 967 athletes, representing 25 different sports, Jensen *et al.* [11] found different values for *b* in each type of sport analyzed. Later, an approximate mean exponent of 0.73 was calculated for all modalities, which permitted the creation of a ranking of aerobic capacity headed by long-distance cyclists and runners.

Assuming that the allometric scale allows a different analysis of the results, there arises the need to analyze the performance of athletes from two distinct types of modality: running and rowing. Considering the specific characteristics of each modality and the body composition of the athletes, the purpose of this study was to determine the allometric exponents for runners and rowers, while analyzing the relationship to performance with and without the use of allometrics.

MATERIALS AND METHODS

Eleven male long-distance runners and fifteen male elite rowers volunteered and were selected for the study. In accordance with the recommendations of the American College of Sports Medicine (ACSM) [1], all the subjects filled out forms with their personal details and read and signed an informed consent form approved by the Research Ethics Committee of the Federal University of Rio Grande do Sul, Brazil. The characteristics of the sample are presented in Table 1. All the athletes were experienced in their respective modalities and they were familiar with treadmill (runners) and rowing ergometry (rowers) tests.

The tests for determination of the $\dot{V}O_2max$ were carried out in the Exercise Research Laboratory of the Physical Education School of the Federal University of Rio Grande do Sul, Brazil. The athletes participated in a progressive workload test until maximum effort, corresponding to the respective modality. Prior to the test, anthropometrical measurements were taken and a body composition evaluation was performed. The body density and percentage of fat were calculated using the protocols from Jackson and Pollock [10] and Siri [16], respectively.

The runners were recommended to perform a brief stretching exercise and, after having been fitted with a heart-rate monitor (Polar S-610) and a gas-collecting mask, they remained seated for roughly ten minutes prior to the start of the treadmill test. A progressive workload test was carried out on a treadmill (Quinton – Seatle, USA). The initial workload (velocity) was 9 $km{\cdot}h^{-1}$ with an increment of 0.5 $km{\cdot}h^{-1}$ each 30 seconds until maximum effort in order to determine the $\dot{V}O_2max$ and the allometric exponent. The workload increments were sufficient for a test duration of 8 -14 minutes.

The criteria used to determine the $\dot{V}O_2max$ were the same as those adopted by Hsi *et al.* [9], which consists of the observation of, at least, two of the following criteria: voluntary request by the subjects, plateau of the oxygen uptake curve and respiratory exchange ratio higher than 1.15.

The rowers performed a maximal test on a progressive rowing ergometer (Concept II - VT, USA) that lasted 5 minutes in each stage. The initial workload was 150 watts with increments of 50 watts for each stage. The test was stopped when the athlete reduced the rowing performance. The criteria utilized to determine the $\dot{V}O_2max$ were the same as those used for the runners. The workload increments were sufficient for a test of 8 -12 minutes.

In order to evaluate oxygen uptake, a mixing-box-type portable Aerosport KB1-C gas analyzer (Ann Arbor, USA) was used.

The allometric exponent was determined from the logarithmic equation $Log\ y = Log + b\ Log\ x$, where *x* is the body mass, *y* is the $\dot{V}O_2max$ ($l{\cdot}min^{-1}$), *a* is one constant and *b* is the allometric exponent. An average exponent was calculated for each group, using the average values of mass and $\dot{V}O_2max$. Thus, a linear equation was obtained together with its respective regression coefficient.

Descriptive statistics were used to analyze the collected data, which are presented as means and standard deviation for each group,

TABLE 1. MEANS AND STANDARD DEVIATION FOR THE AGE, WEIGHT, HEIGHT AND $\dot{V}O_2max$ (ABSOLUTE AND RELATIVE)

	RUNNERS (11)	ROWERS (15)
Age (yers)	22 + 10	24 + 5
Weight (kg)	61.7 + 9.3	83.5 + 7.2
Height (cm)	174 + 8.8	185.5 + 6.5
$\dot{V}O_2max$ absolute ($l{\cdot}min^{-1}$)	3.4 + 0.5	5.1 + 0.4
$\dot{V}O_2max$ relative ($ml{\cdot}kg^{-1}{\cdot}min$-1)	56.3 + 3.9	61.2 + 3.4

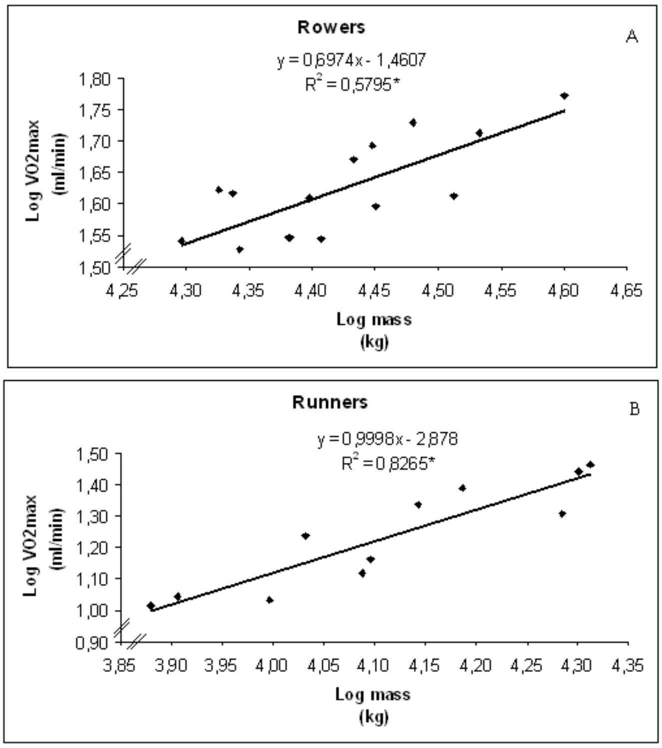

FIG. 1. EQUATION FOR ROWERS (A) AND RUNNERS (B) USED FOR DETERMINING THE ALLOMETRIC EXPONENT WITH P<0,05.

TABLE 2. VALUE OF THE $\dot{V}O_2$submax IN RUNNERS WITH AND WITHOUT THE USE OF THE ALLOMETRIC EXPONENT

RUNNERS (n=11)			
$\dot{V}O_2$submax (l·min^{-1})		$\dot{V}O_2$submax (ml·kg$^{-0.99}$·min-1)	
Runner 01	41.0	Runner 01	42.7
Runner 02	41.5	Runner 02	43.2
Runner 03	43.0	Runner 03	44.8
Runner 04	44.2	Runner 04	46.0
Runner 05	44.6	Runner 05	46.3
Runner 06	45.5	Runner 06	47.4
Runner 07	46.1	Runner 07	48.1
Runner 08	46.5	Runner 08	48.3
Runner 09	46.8	Runner 09	48.8
Runner 10	47.3	Runner 10	49.4
Runner 11	51.2	Runner 11	53.4

TABLE 3. VALUE OF THE $\dot{V}O_2$submax IN ROWERS WITH AND WITHOUT THE USE OF THE ALLOMETRIC EXPONENT

ROWERS (15)			
$\dot{V}O_2$submax (l·min^{-1})		$\dot{V}O_2$submax (ml·kg$^{-0.66}$·min-1)	
Rower 01	36.5	Rower 01	146.5
Rower 02*	37.2	Rower 03	147.4
Rower 03*	37.6	Rower 04	149.8
Rower 04*	37.8	Rower 02	150.7
Rower 05	38.5	Rower 05	152.8
Rower 06*	39.1	Rower 07	153.3
Rower 07*	40.0	Rower 06	154.4
Rower 08	40.4	Rower 08	157.3
Rower 09*	41.0	Rower 10	160.9
Rower 10*	41.2	Rower 15	162.6
Rower 11*	42.1	Rower 14	163.6
Rower 12*	42.3	Rower 13	163.7
Rower 13*	42.6	Rower 12	164.5
Rower 14*	42.8	Rower 09	170.3
Runner 15*	42.9	Rower 11	172.8

Note: (*) Athletes with change in order of performance after application of allometric scale.

with and without the use of the allometric scale. The Shapiro-Wilk test of normality and Levene test of homogeneity were used. The independent T test was used in order to compare the percentage of fat between runners and rowers. The level of significance adopted in this study for all tests was =0.05 (SPSS version 13.0).

RESULTS

The main objective of the present study was to determine the allometric exponents for runners and rowers, which were verified in relation to their performance with and without the allometric application.

The allometric exponent of the rowers was 0.70, with confidence interval between 0.339 to 1.053, and of the runners was 1.00 (isometry), with confidence interval between 0.654 to 1.345, (Fig. 1).

The fat mass percentage of the rowers was 13.6±1.6 and of the runners was 11.9±1.4, with significant differences ($p<0.05$).

The results for performance with and without the use of the allometric exponent are shown in Tables 2 and 3.

All variables investigated in this study (including the logarithmic variables) were normal and homogeneous.

DISCUSSION

The results showed that the rowers had a higher percentage of fat and that this may have influenced the determined the lower allometric exponent found in for this group, as was also observed in the study from Loftin *et al.* [13]. They observed the behavior of the peak values of the $\dot{V}O_2$max in obese and non-obese girls with and without the use of the allometric exponent. The mean allometric exponent found for the non-obese girls was 0.92 while for the obese girls it was 0.46, suggesting an inverse relationship between the value of the allometric exponent and the percentage of fat. Without the use of the allometric exponent, the performance of both groups was similar. However, when the values of body mass were corrected by the allometric method, the difference was 50% lower when the $\dot{V}O_2$ was seen in relation to the body mass.

Similarly, Kusano *et al.* [12] used the allometric scale to examine the effects of the body mass, the lean body mass and the percentage of fat in the performance of females in the indoor obstacles test of the United States Military Academy. They found a high relationship between exponents, absolute and relative body mass, and a proportional relationship between these two variables and the time required to complete the test. It is important to emphasize that these authors based their study on statistical analysis of correlation, while we attempted to find a single exponent that would serve different groups, with intra-group similarities in relation to the level and type of training and body composition, as in as the study of Loftin *et al.* [13]. However, the body composition represents the common ground between these studies. This is due to a tendency of the allometric exponent to decrease when the percentage of fat is higher, and a tendency to approximate the exponent of the unit when the lean mass content is higher. This can be attributed to the fact that fatty tissue is a metabolically less active, contributing less to performance during exercise.

In a previous study by our laboratory, Tartaruga *et al.* [17] highlight the importance of body surface in the development of different mechanical tasks, i.e., the manner by which the body mass of the subject (or animal) is supported during a task as well as the mechanical resistance offered by environment where the task is developed, may interfere in the determination of the allometric exponent. This could explain the low value of *b* for rowers and the differences in percentage of fat. The rowers work in a seated position, unlike the runners, who need support their weight during the race.

Applying the allometric scale allows physiological variables of a specific group to be analyzed taking into consideration their characteristics. Chamari *et al.* [3] collected data for $\dot{V}O_2$max and $\dot{V}O_2$submax in soccer players and young adults and found a single allometric exponent for the two groups with respect to two variables (for $\dot{V}O_2$max $b=0.72$ and for $\dot{V}O_2$submax $b=0.60$). Differences were found when the VO_2 values obtained using the traditional method were compared with those obtained with the application of the allometric scale. In the traditional method, the $\dot{V}O_2$max of adults was underestimated, but no difference was found with respect to young people. However, it was 5% higher when applied the allometric exponent of 0.72. The $\dot{V}O_2$submax of young people was underestimated by 13% when analyzed in the traditional form, though there was no difference from adults when analyzed using the allometric method.

In Tables 2 and 3, rowers and runners, respectively, are shown in order of performance according to $\dot{V}O_2$submax values, i.e., from the most economical to the least economical. For runners, the relations and proportions of performance after the application of allometric scale were retained due to the *b* found for this group, which is very close to the unit. On other hand, among the rowers, with the application of allometric scale, some inversions of the order of performance can be seen in some athletes. Rowers 8 and 9, for example, have values close to $\dot{V}O_2$submax when compared to the traditional method. Nevertheless, from the allometric point of view, while rower 8 remained in the same place in the ranking, the rower 9 became the second least economic in the group. Given these results, there arises a debate on the assessment of the performance of athletes, excluding the technical issues relating to each modality, as the application of the allometric scale allows physiological variables of a specific group to be analyzed while taking into consideration their characteristics, such as body composition, body surface area, level of training, environment of activity, etc [17].

CONCLUSIONS

The application of the allometric scale allows the specific characteristics of the sport practiced by the athlete to be taken into consideration, so that his/her physical condition can be better assessed. Thus, it may be used as a means of investigating, for example, why athletes with very similar physiological values perform so differently in races or, conversely, why athletes with different physiological values produce similar performances, so making it one more evaluation method to be used by coaches.

On some occasions, athletes from the same team have very similar physiological and technical characteristics, though one may perform better than another, even when there is no significant difference in $\dot{V}O_2$submax and, possibly, economy of movement. The allometric scale can facilitate inter-comparison of the subjects.

Scaling may help both in understanding variation in aerobic power and in defining the physiological limitations of work capacity.

Acknowledgments

This research was supported in part by a grant from CNPq and CAPES – Brazil. .

REFERENCES

1. Balady G.J., Berra K.A., Golding L.A., Gordon N.F., Mahler D.A., Myers J.N., Sheldahl L.M. Guidelines for Exercise Testing and Prescription. ACSM, 2000.
2. Brisswalter J., Legros P., Durand M. Running economy, preferred step length correlated to body dimensions in elite middle distance runners. J. Sports Med. Phys. Fitness 1996;36:7-15.
3. Chamari K., Moussa-Chamari I., Boussaidi L., Hachana Y., Kaouech F., Wisloff U. Appropriate interpretation of aerobic capacity: allometric scaling in adult and young soccer players. Br. J. Sports Med. 2005;39:97-101.
4. Daniels J., Oldridge N., Nagle F., White B. Differences and changes in vo2 among young runners 10 to 18 years of age. Med Sci Sports 1978;10:200-203.
5. Darveau C.A., Suarez R.K., Andrews R.D., Hochachka P.W. Allometric cascade as a unifying principle of body mass effects on metabolism. Nature 2002;417(6885):166-170.
6. Denadai B.S. Consumo máximo de oxigênio: fatores determinantes e limitastes. Rev. Brasileira Atividade Fís. Saúde 1995;1:85-94.
7. Gillooly J.F., Brown J.H., West G.B., Savage V.M., Charnov E.L. Effects of size and temperature on metabolic rate. Science 2001;293(5538):2248-2251.
8. Goosey-Tolfrey V.L., Batterham A.M., Tolfrey K. Scaling behavior of VO2peak in trained wheelchair athletes. Med. Sci. Sports Exerc. 2003;35:2106-2111.
9. Hsi W.L., Lan C., Lai J.S. Normal standards for cardiopulmonary responses to exercise using a cycle ergometer test. J. Formos Med. Assoc. 1998;97:315-322.
10. Jackson A.S., Pollock M.L. Generalized equations for predicting body density of men. Br. J. Nutr. 2001;40:497-504.
11. Jensen K., Johansen L., Secher N.H. Influence of body mass on maximal oxygen uptake: effect of sample size. Eur. J. Appl. Physiol. 2001;84:201-205.
12. Kusano M.A., Vanderburgh P.M., Bishop P. Impact of body size on women's military obstacle course performance. Biomed. Sci. Instrum. 1997;34:357-362.
13. Loftin M., Sothern M., Trosclair L., O'hanlon A., Miller J., Udall J. Scaling VO_2 peak in obese and non-obese girls. Obes. Res. 2001;9:290-296.
14. Powers S.K., Howley E.T. Exercise Physiology: theory and application to fitness and performance. 4 Ed. Mc Grall Hill, Boston 2000.
15. Saltin B., Astrand P.O. Maximal oxygen uptake in athletes. J. Appl. Physiol. 1967;23:353-358.
16. Siri W.E. Body composition from fluid spaces and density. National academy of science. Washington, USA, 1961.
17. Tartaruga M.P., Peyré-Tartaruga L.A., Coertjens M., Medeiros M.H.D., Kruel L.F.M. The influence of the allometric scale on the relationship between running economy and biomechanical variables in distance runners. Biol. Sport 2009;26:263-273.
18. West G.B., Brown J.H., Enquist B.J. A general model for the origin of allometric scaling laws in biology. Science 1997;276(5309):122-126.
19. White C.R., Seymour R.S. Sample size and mass range effects on the allometric exponent of basal metabolic rate. Comp. Biochem. Physiol. A 2005;142:74-78.