RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DOI: http://dx.doi.org/10.5007/1980-0037.2014v16n6p709

point of view

New horizons for aerobic fitness normalization in children: Breaking the paradigm

Novos horizontes para a normalização da aptidão cardiorrespiratória em crianças: Quebrando o paradigma

Giovani dos Santos Cunha[1,2]
Gabriela Tomedi Leites[1]
Brian Weldon Timmons[1]

Abstract – Traditional methods to normalize aerobic fitness (VO_{2max}) have been considered inadequate for not properly adjusting the effects of body size in children, adolescents and adults. Allometric scaling ($Y=aX^b$) has emerged as an efficient method to compare individuals of different body dimensions. Studies aimed to compare VO_{2max} in individuals with different body sizes should use methodology that properly accounts for the body size effect, thereby avoiding misinterpretation and reaching the potentially wrong conclusion. The use of allometric scaling for studies aimed to compare aerobic fitness in children and adolescents who dramatically vary in body size is strongly recommended.

Key words: Allometry; Body composition; Oxygen uptake.

Resumo – *Métodos tradicionais de normalização da aptidão cardiorrespiratória (VO_{2max}) têm sido considerado inadequados por não ajustarem adequadamente os efeitos do tamanho corporal em crianças, adolescentes e adultos. A alometria ($Y=aX^b$) tem demonstrado ser um eficiente método para comparar indivíduos com diferentes dimensões corporais. Estudos que desejam comparar o VO_{2max} em indivíduos heterogêneos em tamanho corporal deveriam usar uma metodologia que ajuste apropriadamente o efeito do tamanho corporal, evitando, assim, interpretações errôneas e conclusões equivocadas. Desta forma, recomendamos fortemente a aplicação de escalas alométricas em estudos que tenham como objetivo comparar a aptidão cardiorrespiratória em crianças e adolescentes com diferentes tamanhos corporais.*

Palavras-chave: *Alometria; Composição corporal; Consumo de oxigênio.*

1 McMaster University. Child Health & Exercise Medicine Program. Hamilton, Ontario. Canada

2 Federal Institute of Education Science and Technology Farroupilha. Alegrete, RS. Brazil

Received: 13 March 2014
Accepted: 09 July 2014

INTRODUCTION

The oxidative and anaerobic capacity exhibited by skeletal muscle during the growth course and biological maturation is a subject of considerable debate[1,2], as the effects of growth and biological maturation on energy metabolism are not yet clear. Exercise physiologists are faced with the challenge of determining whether changes in physiological performance variables, such as VO_{2max}, are more related to normal growth and development or can be significantly altered by changes in physical activity levels. Indeed, such comparisons between groups or individuals' performance and their peers have been confounded by the body size effect[3-6].

A recent study published in the Brazilian Journal of Kinantropometry and Human Performance determined the influence of sexual maturation and physical activity level on cardiorespiratory fitness of schoolchildren of both sexes aged 9-14 years[7]. This study showed the influence of maturation on aerobic fitness. Estimated VO_{2max} values were different among maturation stages in both sexes, and between sexes at the same maturation stage. Absolute VO_{2max} ($L \cdot min^{-1}$) values increased with the advance of biological maturation, while relative VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) values showed a decreasing trend, in girls only. The influence of biological maturation on VO_{2max} was estimated at 7%. The authors hypothesized that the influence of sexual maturation on VO_{2max} may be related to lower PFK activity, a key glycolytic enzyme. However, this hypothesis could only be accepted if the prepubertal group had presented lower values of relative estimated VO_{2max} compared to pubertal and postpubertal groups. In addition, this study did not examine whether the ratio standard ($ml \cdot kg^{-1} \cdot min^{-1}$) appropriately adjusted for the body size effects on VO_{2max}. For this reason, it is not possible to determine whether biological maturation truly had an effect on VO_{2max} or whether the results were affected by a phenomenon called scaling denominator.

One must be very careful in *interpreting* the effects of biological maturation on aerobic fitness, as many studies have failed to use an appropriate method to adjust or control for body size effects[5,8]. Body size has paramount importance for the understanding the effects of biological maturation and growth on aerobic fitness because it serves as the main normalizing variable. Nevertheless, there are many theoretical and statistical limitations to the standard ratio used to adjust confounding effects associated with body size. With ratio standard analysis, it is assumed that VO_{2max} is normalized for body mass effects. However, VO_{2max} is often overestimated in individuals with low body mass and underestimated in those with high body mass[4,6,9]. The main reason for this is because oxygen consumption increases at a slower rate than body mass[3,4].

For this reason, some authors have suggested using allometric scaling ($Y=aX^b$) to facilitate body size comparisons of performance variables between heterogeneous groups[3-5,8]. Exponent b can be estimated by means of linear regression analysis after calculating the logarithm of the power function according to $\log Y = \log a + b \log X$, where Y corresponds

to the value of the dependent variable (in this case, absolute VO_{2max}), X corresponds to the independent variable (body size), *a* is a scaling constant, and *b* is the exponent value relative to body size[3-5,8,9].

The purpose of this point-of-view was to highlight the importance of appropriately normalizing aerobic fitness in heterogeneous populations, such as children and adolescents. Breaking the paradigm of traditional ratio standards using body mass as the denominator would avoid possible misinterpretations in the development of aerobic fitness during growth.

DISCUSSION TOPICS

Although the traditional method for VO_{2max} normalization ($ml \cdot kg$ body $mass^{-1} \cdot min^{-1}$) is broadly used in literature, is this the best way to compare and identify the effects of biological maturation, growth, and sex on aerobic fitness in children and adolescents? The traditional method to normalize aerobic fitness has been found to be inefficient and may lead to misinterpretations when physiological variables between groups of individuals with different body sizes and composition are compared[3-6,8,9].

Currently, there are alternatives that seem to be more appropriate to avoid the confounding effects of body size and body composition on performance variables[10]. To elucidate the VO_{2max} behavior during childhood, Welsman et al.[3] used standard and allometric scaling to adjust the effects of body mass on VO_{2max} in prepubescent, pubescent, and adult individuals. No difference among groups was found when VO_{2max} was normalized by the standard value, and this result corroborated the literature at that time. Conversely, the allometric analysis ($ml \cdot kg^{-0.80} \cdot min^{-1}$) found a progressive increase in VO_{2max} among groups, and these findings altered the conventional interpretation of the behavior of VO_{2max} during childhood and adolescence. Similarly, Cunha et al.[4] showed that absolute VO_{2max} ($ml \cdot min^{-1}$) was higher in post-pubescent than in pubescent boys. Biological maturation and body mass can explain 73.5% of the variance of absolute VO_{2max}. Although VO_{2max} relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$) was similar among groups, the effects of body mass on the variation of VO_{2max} values remain even after this normalization (5.1%). This result demonstrated that VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) is not independent of body mass. On the other hand, VO_{2max} normalized by a derived allometric exponent ($ml \cdot kg^{-0.90} \cdot min^{-1}$) was higher in postpubertal compared to pubertal boys and the values were considered independent of body mass. Nevertheless, these differences could not be attributed to biological maturation or to any other variable that compose the multiple linear regression analysis. The authors concluded that VO_{2max} ($ml \cdot kg^{-0.90} \cdot min^{-1}$) was independent of biological maturation, chronological age, body mass, stature, and years of training.

Some studies have used muscle volume (MV), free fat mass (FFM), total muscle mass or lower limb muscle mass as normalizing variables in the attempt to adjust for differences in body dimensions[6,8,11,12]. These variables were chosen to reflect the reality that under maximal intensity exercise,

90% of blood flow and VO_2 are allocated to ATP synthesis during muscle contraction. Therefore, the active muscle mass during exercise may be an even more appropriate variable to normalize VO_{2max}[13]. Similarly, other studies have used MV to normalize VO_{2max}, since MV better represents the active muscle mass during exercise[8,11,12]. Welsman et al.[11] found that VO_{2max} and power were higher among boys compared to girls using body mass, whereas no significant difference was found between sexes when data were normalized by MV using either ratio or allometric scaling. These authors suggested that boys and girls exhibit similar aerobic and anaerobic performance when data were adjusted for MV using the following scaling factors: Liters of $O_2 \cdot L\ MV^{-0.55} \cdot min^{-1}$ and $Watts \cdot L\ MV^{-1.2}$, respectively. Tolfrey et al.[8] also analyzed the influence of body size on VO_{2max} in boys and men using body mass, FFM, and lower limb MV as normalizing variables for VO_{2max}. In boys, VO_{2max}/kg body mass$^{0.79}$ and VO_{2max}/kg FFM$^{1.00}$ did not completely remove the effect of these variables on VO_{2max}. Conversely, when VO_{2max} was normalized to MV (VO_{2max}/L $MV^{0.64}$), this effect was fully adjusted. In this study, allometric scaling to MV was the most appropriate approach to normalize VO_{2max} in boys and men.

Recent studies have shown that biological maturation has no effect on aerobic fitness variables in children and adolescents[4,14,15], when body dimensions are appropriately normalized[4,14,15]. The evidence shows that the historical approach to normalizing VO_{2max} to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$) seldom completely accounts for its effect on fitness.

FINAL COMMENTS

We strongly recommend the use of allometric scaling for studies whose aim is to investigate the impact of growth on aerobic fitness of children and adolescents.

Acknowledgements

The authors Giovani dos Santos Cunha and Gabriela Tomedi Leites were supported by a scholarship from the Brazilian Council of Science and Technology (CNPq, Program Science Without Borders – CsF)

REFERENCES

1. Dotan R, Falk B. Commentaries on Viewpoint: Do oxidative and anaerobic energy production in exercising muscle change throughout growth and maturation? Manifestations of a common underlying cause. J Appl Physiol 2010;109(5):1565.
2. Ratel S, Tonson A, Cozzone PJ, Bendahan D. Do oxidative and anaerobic energy production in exercising muscle change throughout growth and maturation? J Appl Physiol 2010;109(5):1562-4.
3. Welsman JR, Armstrong N, Nevill AM, Winter EM, Kirby BJ. Scaling peak VO2 for differences in body size. Med Sci Sports Exerc 1996; 28(2):259-65.
4. Cunha G, Lorenzi T, Sapata K, Lopes AL, Gaya AC, Oliveira A. Effect of biological maturation on maximal oxygen uptake and ventilatory thresholds in soccer players: An allometric approach. J Sports Sci 2011;29(10):1029-39.

5. Nevill AM, Bate S, Holder RL. Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. Am J Phys Anthropol 2005; (41):141-53.
6. Leites GT, Sehl PL, Cunha GD, Detoni Filho A, Meyer F. Responses of Obese and Lean Girls Exercising under Heat and Thermoneutral Conditions. J Pediatr 2013; 162(5):1054-60.
7. Soares NMM, Silva RJS, Melo EV, Oliveira ACC. Influence of sexual maturation on cardiorespiratory fitness in school children. Rev Bras Cineantropom Desempenho Hum 2014;16 (2):223-32.
8. Tolfrey K, Barker A, Thom JM, Morse CI, Narici MV, Batterham AM. Scaling of maximal oxygen uptake by lower leg muscle volume in boys and men. J Appl Physiol 2006;100(6):1851-6.
9. Cunha GS, Célia FG, Ribeiro JL, Oliveira AR. Effects of the biological maturation on maximal oxygen uptake and ventilatory breakpoint of Brazilian soccer players Gazz Med Ital - Arch Sci Med 2008;167(2):43-9.
10. Cunha GS, Vaz MA, Reischak-Oliveira A. Normalization of muscle strength and torque in children and adolescents. Rev Bras Cineantropom Desempenho Hum 2011; 13(6):468-76.
11. Welsman JR, Armstrong N, Kirby BJ, Winsley RJ, Parsons G, Sharpe P. Exercise performance and magnetic resonance imaging-determined thigh muscle volume in children. Eur J Appl Physiol Occup Physiol 1997;76(1):92-7.
12. Nevill AM, Markovic G, Vucetic V, Holder R. Can greater muscularity in larger individuals resolve the 3/4 power-law controversy when modelling maximum oxygen uptake? Ann Hum Biol 2004;31(4):436-45.
13. Baker JS, Davies B. Quantification of active muscle mass during experimental exercise. J Appl Physiol 2006;101(5):1534.
14. McNarry MA, Welsman JR, Jones AM. Influence of training and maturity status on the cardiopulmonary responses to ramp incremental cycle and upper body exercise in girls. J Appl Physiol 2011;110(2):375-81.
15. McNarry MA, Welsman JR, Jones AM. The influence of training and maturity status on girls' responses to short-term, high-intensity upper- and lower-body exercise. Appl Physiol Nutr Metab 2011;36(3) 344-52

Corresponding author

Giovani dos Santos Cunha
Federal Institute of Education Science and Technology Farroupilha, RS-377, km 27 Street.
Zip Code: 97555-000 Alegrete. RS. Brazil.
Email: giovanicunha@yahoo.com.br