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Human Kinetics
LETTER TO THE EDITOR

Interpreting the Persistence of the VO_2 Ratio-Scaling Fallacy

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Dear Editor,

Until the 70s of the 20th century, exercise science was, overwhelmingly, centered around adults and, even when understood, allometric scaling was hardly ever critical because adults are all mature and their body masses do not greatly differ. The subsequent advent of *Pediatric Exercise Science* was largely based on following the trodden path of the reigning adult discipline. This probably explains why *Pediatric Exercise Science* has never really paused to heed what in the biological sciences has been common knowledge for nearly a century.

Kleiber (7) was not even the first to point out, already in 1932, that per unit mass, smaller animals have higher metabolic rate, which in turn, better relates to the body's surface area than to its mass. This relationship is the source of the 0.67 body-mass exponent, often used in comparing different-sized animals. Also, it has been well established that young, growing animals have considerably higher basal metabolic rates than their mature counterparts. In 1936, Boothby et al (5) of the Mayo clinic showed this to be true for humans, as well. In 1949, Tanner (8) was the first to expressly address the ratio-scaling fallacy in relation to the evaluation of human development.

Welsman and Armstrong, with cooperation of others at the Children's Health and Exercise Research Centre at the University of Exeter, ought to be credited with taking up the allometric challenge that had been raised, with little consequence, by Tanner. In a nearly 3-decade-long string of publications, the first of which published in 1991 (4), the group has been raising awareness of the significance of allometric scaling with admirable evangelistic persistence. In their customarily well-written and referenced article, "Interpreting Aerobic Fitness in Youth: The Fallacy of Ratio scaling" (10), Welsman and Armstrong strive again to drive home the message that simply dividing oxygen consumption by body weight (ratio scaling) is conceptually and clinically wrong, and to extol the virtues of allometric scaling.

Although the article's "gospel" is both justified and welcome, a few of its aspects and the absence of others exemplify the main reasons for why, 70 years after Tanner's observations, ratio scaling is, overwhelmingly, still the de facto scaling method of choice in 2019. Of course, a major reason is the hard-to-resist conceptual and practical simplicity of ratio scaling, but let us proceed to examine some other more fundamental reasons.

Lack of Alternatives

It is not laziness or convenience that makes potential users shy away from allometric scaling. Currently, there simply is no credible method of doing so, and Welsman and Armstrong do not bring us any closer to having one. This is rather curious because in 2 concurrent publications, one in the very same *Pediatric Exercise Science* issue, the authors use multilevel regression analysis to chart a potential tool by which to incorporate the various factors that could modify the basic, body weight–based allometric exponent (2,3). Indeed, even in the numerous publications emanating from their own research center (many of which referenced in this study), the authors persist in using ratio scaling with no practical alternative.

Adiposity and Lean Body Mass

Adiposity has long been recognized as a confounding factor in affecting meaningful interpretations of aerobic power. Indeed, scaling VO_2 by lean body mass (LBM) rather than gross body mass is often opted for. Although it does not address the core issue inherent to allometric scaling, LBM scaling does nevertheless demonstrate common awareness that simple ratio scaling may not be appropriate. In justifying their aversion to ratio scaling, Welsman and Armstrong argue that "the simple ratio standard ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) does not remove the influence of body mass if the ratio remains significantly, negatively correlated with body mass." It would have been more to the point if the authors stated that ratio scaling does not remove the influence of fat mass, rather than body mass. As stated, however, the statement is unnecessary or even misleading. Even if the relationship between maximal oxygen consumption (VO_2max) and LBM (or muscle mass) was perfectly linear, VO_2max would still be significantly correlated with body mass as Kleiber (7) has already explained in 1932, pointing out that this is "because, on the average, the heavier persons are also the stouter and probably fatter ones."

The authors could have shed more light on the true relationship between size and metabolic rate by controlling for adiposity (or LBM) in their Table 1 data, by calculating the respective exponents, and by contrasting them with the corresponding values they calculated for gross body mass. As the authors accounted for adiposity elsewhere (2,3), it is perplexing why they chose to skip this as well as other factors in the present article.

Age and Maturity

The same holds true for age and maturity. Why is it not dealt with? A major question the authors have apparently not addressed anywhere is how to factor in both variables that have a markedly irregular, nonlinear interrelationship. It is not readily clear that even the multilevel regression approach could properly address this problem, which is further confounded by the fact that the pubertal process not only commences and ends at different ages within and between sexes but also has varied rates in different individuals.

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Resting Metabolic Rate Versus VO_2max

The noted relationship between body's surface area and metabolic rate and its ~0.67 associated mass exponent, found quite valid in many warm-blooded vertebrates, has been based on basal or resting metabolic rate (RMR). The relationship between RMR- and VO_2max-based allometry is not necessarily a straightforward one. Apparently, there is a general correlation between the RMR and VO_2max relationships to body mass. Dutenhoffer and Swanson (6), for example, found a .86 correlation, explaining 74% of observed variance across a 7-fold range of body masses of several bird species. However, Taylor et al (9) reported "a great variability in VO_2max among domestic species of the same size, horse and dog having a VO_2max more than 3 times that of a cow and sheep, respectively." Importantly, they also reported the mean allometric body mass exponent, for 23 species of wild and domestic animals, to be 0.845, which is quite different than the 0.67 to 0.75 typically observed range of the corresponding RMR exponents. As the range of human VO_2max values, for children or adults of similar body masses and adiposities, can approach or exceed a 2-fold, there is no reason to presume that the corresponding allometric exponents would be similar.

Fitness and Training

Aerobic-fitness differences could considerably change the relationship between VO_2max and size, age, or maturity, in a given individual compared with another. Aerobic training can augment this difference when performed by an innately fit individual or diminish it when done by a low-fit one. How would such differences contribute to the ultimate allometric relationship? The elucidation of these fitness/training effects could have been helped had the authors compared derived exponents between highly fit or trained individuals and their untrained or low-fitness peers.

Is Simple Ratio Scaling Always Wrong?

In promoting allometric scaling, in this and their other publications, the authors seem to convey the message that it is the ultimate and the only appropriate scaling methodology. This is misleading. The authors' quest of formulating a biologically faithful representation of aerobic-power development during maturation does not cover the entire realm of VO_2 testing and scaling. Many, if not most VO_2max tests are performed, not for the sake of pediatric exercise science, but rather for *functional* assessment and comparisons of performance capacity in activities in which the carried weight of the body is a major determining factor. In fact, in a seemingly unrelated 2015 article, Armstrong et al (1) demonstrated awareness of the issue by commenting that the ratio scaling "methodology is informative in relation to the performance of youth athletes who carry their body mass (eg, track athletes)." Although body mass may not be the only relevant factor in activities of this nature, simple ratio scaling is still the best scaling methodology to reflect functional capacity in such cases.

Unresolved Complexity

The main reason, however, that a practical allometric methodology is still absent and that the "fallacy of ratio scaling" is not gaining much traction despite its 70 years of conceptual history, is its unresolved complexity. In their aforementioned concurrent publications (2,3), Armstrong and Welsman proceed in the right direction by employing a multilevel-regression approach for factoring in the contributions of various factors to the body-mass–VO_2max relationship. Unfortunately, the factors of fitness and training, age and maturity, as well as the RMR-VO_2max relationship, are not addressed at all. Admittedly, with 2 sexes, a 9-year developmental age span, and even the incomplete list of considered factors, even the 1057-VO_2max-test database lacks the statistical power for a robust determination of how the numerous relevant factors ought to be incorporated into a composite allometric exponent of body mass.

The challenge of configuring the proper exponent is starkly exemplified by the data presented in Table 1. The authors revisited 13 studies, comprising 20 study cohorts and incorporating 958 treadmill-only VO_2max tests of 11- to 18-year-old participants of both sexes. For each study cohort, they then calculated the best (allometric) exponent to eliminate VO_2max's dependence on body mass (ie, minimize the correlation between body mass and the resulting allometric VO_2max). As noted earlier, it is unclear why the authors chose not to incorporate analysis of any additional factors, despite the information being available and their acknowledging "that additional factors affect peak VO_2." Even so, the span of 0.37 to 0.94 of calculated allometric exponents constitutes an enormous, 7-fold difference in "corrected" VO_2max for a 30-kg child (8.8-fold for a 45-kg lad). Moreover, if sex was expected to make a difference, this was not borne out by the presented data, as the mean allometric exponents for the 9 male and 11 female cohorts were identical: 0.64.

The Message

The fact that ratio scaling is not the best manner by which to accommodate differing body masses and age/maturity levels in respect to metabolic rate, has been well recognized since early in the 20th century. The fact that ratio scaling has been and still is abused is quite clear as well. However, whether or not ratio scaling is a fallacy greatly depends on whether one is interested in the developmental aspects of VO_2max, or rather in evaluating performance capacity in weight-bearing sports or other activities. Much larger and more varied databases, possibly via multicentered studies, are needed to come up with a better, usable model that most users could agree upon and support. At this point, however, the continued rehashing of allometric scaling, without providing a tentative working model that incorporates at least most of the relevant factors, is destined to add confusion rather than clarity to this important but complex issue. Until then, ratio-scaled VO_2 will continue to muddy the pediatric exercise scene whether we like it or not.

References

1. Armstrong N, Barker AR, McManus AM. Muscle metabolism changes with age and maturation: how do they relate to youth sport performance? *Br J Sports Med*. 2015;49:860–4. PubMed ID: 25940635 doi:10.1136/bjsports-2014-094491
2. Armstrong N, Welsman J. Development of peak oxygen uptake from 11–16 years determined using both treadmill and cycle ergometry. *Eur J Appl Physiol*. 2019;119:801–12. PubMed ID: 30627827 doi:10.1007/s00421-019-04071-3
3. Armstrong N, Welsman J. Sex-specific longitudinal modeling of youth peak oxygen uptake. *Pediatr Exerc Sci*. 2019;31(2):204–212. doi:10.1123/pes.2018-0175