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Human Kinetics
EDITOR'S NOTE

Youth Aerobic Fitness

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Aerobic (or cardiorespiratory or cardiopulmonary) fitness reflects the integrated ability to deliver oxygen from the atmosphere to the skeletal muscles and to utilize it to generate energy to support muscle activity during exercise. Aerobic fitness is the most researched physiological variable in the history of pediatric exercise science, but its assessment, interpretation, and relationship with current and future health remain topics of lively debate as evidenced by this Special Issue of *Pediatric Exercise Science*.

Maximal oxygen uptake ($\dot{V}O_2$max), the highest rate at which an individual can consume oxygen during exercise, limits the performance of aerobic exercise and is internationally recognized as the best single measure of adults' aerobic fitness. $\dot{V}O_2$max serves as a biomarker for the development and severity of various health outcomes, and a high $\dot{V}O_2$max is a pre-requisite for elite performance in many sports. However, $\dot{V}O_2$max does not define all aspects of aerobic fitness. Cardiopulmonary exercise tests (CPETs), which rely solely on $\dot{V}O_2$max, may mask clinical insights that can be gleaned from submaximal data and/or relationships between physiological variables. Similarly, in several sports and in everyday life, the ability to engage in rapid changes in exercise intensity is at least as important as $\dot{V}O_2$max and best described by the transient kinetics of pulmonary $\dot{V}O_2$.

The first scientist to attempt to measure $\dot{V}O_2$ during exercise was Antoine-Laurent Lavoisier in the 1770s, but it is the work of Archibald Vivian Hill in the 1920s, which is generally credited with introducing the concept of $\dot{V}O_2$max to exercise science (30). By the late 1930s, data purporting to describe the $\dot{V}O_2$max of boys had been reported (41), and in 1952, Åstrand (10) published his seminal studies of the "physical work capacity" of both boys and girls. Åstrand noted that only 70 of the 140 schoolchildren he tested using a discontinuous, incremental exercise protocol to voluntary exhaustion satisfied the conventional $\dot{V}O_2$ plateau criterion for confirming achievement of $\dot{V}O_2$max. This phenomenon was largely ignored for decades, and when it was addressed and the term peak $\dot{V}O_2$ introduced, it was often rejected by scientific journals as being a reflection of failure to elicit maximal values of $\dot{V}O_2$ in children.

It is challenging to interpret aerobic fitness during childhood and adolescence as changes in growth and maturation governed by the running of individual biological clocks must be accounted for. Typically, pediatric exercise scientists and clinicians have ignored maturity status and addressed changes in body size by attempting to "control" for body mass. In the first laboratory investigation of boys' "physical fitness," Robinson (41), without a scientific rationale or statistical justification, presented his $\dot{V}O_2$ data in ratio with body mass (ie, in $mL\cdot kg^{-1}\cdot min^{-1}$) and initiated an approach for "controlling" the children's body mass that has continued to the present day. In 1949, Tanner (50) demonstrated the fallacy of 1:1 ratio scaling with body mass and showed how spurious relationships emerge when these data are correlated with other health-related variables. Subsequent studies using allometric analyses revealed how simply dividing peak $\dot{V}O_2$ with body mass has not only confounded understanding of the development of aerobic fitness (eg, 6,9,58) but also misinterpreted its relationship with markers of youth health (eg, 8,31,36). Yet, the vast majority of published articles still report young people's peak $\dot{V}O_2$ in ratio with body mass (15), and the spurious use of these data in subsequent statistical analyses with other health-related variables persists (36).

In an Invited Symposium at the 1999 Conference of the American College of Sports Medicine (subsequently published as a Special Issue of *Pediatric Exercise Science*), it was argued that despite over 60 years of intensive investigation, the assessment and interpretation of youth aerobic fitness is shrouded in controversy (5). Twenty years later, the topic is still contentious; the vast majority of published data are cross-sectional and well-designed longitudinal studies are sparse. Peak $\dot{V}O_2$ is now recognized as the "gold-standard" measure of young people's aerobic fitness, but pediatric exercise scientists continue to wrestle with factors related to its rigorous determination. By contrast, there is a view that relying predominantly on maximal values in CPETs obfuscates clinically useful insights that can be obtained from submaximal data and innovative data analytics. Some researchers suggest that the responses of physiological variables at the onset and/or offset of an exercise challenge may be as (or more) important than peak effort. Others promote the estimation of peak $\dot{V}O_2$ from field test performance scores as a valid alternative to rigorous determination of peak $\dot{V}O_2$. Some writers advocate the use of fixed values of peak $\dot{V}O_2$ in ratio with body mass to identify "clinical red flags" for 8- to 18-year-olds. On the other hand, some scientists believe that to elucidate the development of aerobic fitness and its relationship with present and future health, it must be interpreted in relation to sex-specific, concurrent changes in a range of chronological age- and maturity status–driven morphological and physiological variables. These issues are addressed in the reviews, commentaries, letters, and original research papers presented in this timely Special Issue of *Pediatric Exercise Science*.

Peak Oxygen Uptake

In the opening review, Falk and Dotan (24) provide a perceptive analysis of the principal issues relating to the measurement of peak $\dot{V}O_2$. Methodological factors such as treadmill and cycle ergometry, exercise test protocols, and respiratory gas collection and analysis are critically examined. Potential pitfalls are identified, and the need for scientific rigor in the determination of peak $\dot{V}O_2$ is

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stressed. The distinction between $\dot{V}O_2$max and peak $\dot{V}O_2$ is clarified, the widespread use of secondary criteria to confirm a maximal effort is questioned, and the efficacy of verification tests of peak $\dot{V}O_2$ is discussed. Falk and Dotan (24) cite the research of Barker et al (14) who proposed that to confirm a maximal value of $\dot{V}O_2$, following completion of a ramp test to voluntary exhaustion, participants should undergo a verification test at an exercise intensity of 105% of the peak power output in the ramp test. In a research article in this Special Issue, Barker and colleagues (46) further develop their original work and conclude that the utility of a verification test to confirm that maximal values of $\dot{V}O_2$ attained in a preceding ramp test is not affected by sex, body mass, or fitness status. They recommend that use of a verification test should replace secondary criteria (ie, predicted values of heart rate, respiratory exchange ratio, or blood lactate accumulation) in confirming maximal values of $\dot{V}O_2$. Interestingly, a proposal to adopt verification tests with adults (39) has recently stimulated a lively discussion elsewhere (11,20,40).

Falk and Dotan (24) comment that although it makes little sense, numerous published reviews group together data from treadmills, cycle ergometers, and field test predictions of aerobic fitness to describe typical values of peak $\dot{V}O_2$. They reinforce the view that credible international "norms" for youth aerobic fitness are not available and emphasize that published norms of peak $\dot{V}O_2$ should be treated with caution, as they do not accommodate maturity status and related body size differences that directly affect $\dot{V}O_2$. The authors note that ratio scaling does not usually account for body mass and conclude that due to large changes during maturation properly accounting for body mass is essential.

Welsman and Armstrong (57) take up the challenge of interpreting cross-sectional peak $\dot{V}O_2$ data in relation to body mass. They demonstrate that although body mass can be appropriately controlled for using allometric scaling, the current practice of dividing young people's peak $\dot{V}O_2$ with body mass is not founded on a sound scientific or statistical rationale. They outline the history of the adoption and use of ratio scaling in pediatric exercise science and comment that they know of no other scientific discipline where a "convenient and traditional" but evidently fallacious statistical method is recognized by scientific journals as an acceptable alternative to rigorous statistical justification. They explain the statistical assumptions on which ratio scaling is based and draw on ~1000 peak $\dot{V}O_2$ determinations from 20 of their published cross-sectional studies to demonstrate empirically that the assumptions are rarely met in groups of young people. They emphasize that if the use of ratio scaling cannot be demonstrated to appropriately describe young people's aerobic fitness, then any comparisons, conclusions, or recommendations based on ratio-scaled peak $\dot{V}O_2$ are likely to be spurious. They suggest that children and adolescents with levels of aerobic fitness which raise "clinical red flags" based on peak $\dot{V}O_2$ divided by body mass should be investigated not for cardiovascular risk but for what Tanner referred to as "no more formidable a disease than statistical artefact" (50, p. 3).

In a Letter to the Editor in response to Welsman and Armstrong's Commentary, Blais et al (16) comment that they too, "have observed, with some disbelief, the ongoing and widespread utilization of ratio scaling with body mass, despite overwhelming scientific evidence of its many drawbacks." They outline their development of equations based on multivariate regression models that predict means and range of normality that are independent of sex and body size. Recognizing the critical importance of data interpretation in clinical practice, Blais et al (16) indicate that they are currently testing the prediction equations, derived from cycle ergometer tests with healthy youth, in children with congenital heart diseases and cardiomyopathies to assess their diagnostic and prognostic values. Welsman and Armstrong (56) welcome both the supportive comments and the exploration of new methodology, which they hope will encourage others to reconsider how they interpret youth aerobic fitness and avoid spurious correlations with other health-related variables. Welsman and Armstrong (56) reiterate how they have persistently demonstrated that even with cross-sectional studies, there is a need to concurrently control for age, maturity status, and a range of morphological variables but argue that longitudinal studies are required to effectively interpret developmental changes in aerobic fitness. They refer readers to their recent multiplicative allometric modeling articles in this Special Issue and elsewhere.

In their research article focusing on longitudinal data, Armstrong and Welsman (7) further develop their Commentary on cross-sectional data and apply a multiplicative allometric modeling approach to 1057 determinations of 10- to 18-year-olds' peak $\dot{V}O_2$. The multilevel models enable the effects of age, body mass, fat-free mass, and maturity status to be partitioned concurrently within an allometric framework to provide a flexible and sensitive interpretation of the development of peak $\dot{V}O_2$. The baseline model shows that body mass and body fatness controlled for peak $\dot{V}O_2$ is higher in boys than in girls and increases with age in both sexes with the age effect smaller in girls. Sex-specific models illustrate that the ratio-scaled peak $\dot{V}O_2$ interpretation of age-related aerobic fitness is specious and expose the fallacy of using ratio-scaled data as "clinical red flags" or age-related norms. The data demonstrate that, in direct conflict with the ratio-scaled interpretation of aerobic fitness, with body mass controlled for both age and maturity status, they have positive effects on peak $\dot{V}O_2$. Moreover, the modeled data show that it is maturity status–driven fat-free mass, and not body mass, which is the most powerful morphological influence on the development of peak $\dot{V}O_2$.

Field Performance Tests

In his Editor's Notes in the first volume of *Pediatric Exercise Science*, Founding Editor Tom Rowland commented that "there is little in the field of pediatric exercise that has stimulated as much emotional debate as the components, interpretation, and values of mass physical fitness testing of children and youth" (42, p. 289). He initiated a dialog in *Pediatric Exercise Science* (see 38,48), which is rekindled in the present issue by Jo Welsman (55). In her Commentary, she notes that articles predicting aerobic fitness from field performance scores have percolated through *Pediatric Exercise Science* for 30 years and argues that it really is time to move on from mass performance testing and focus on scientific rigor, or as Rowland (43) pithily commented in 1995, "The horse is dead. Let's dismount." By contrast, Tomkinson et al (53) have, through the assembly of large international data sets, stimulated a resurgence of interest in field performance tests, in particular the 20-m shuttle run test (20mSRT). Despite a recent meta-analysis revealing that over half of published correlation coefficients between 20mSRT performance scores and children's peak $\dot{V}O_2$ explain less than 50% of the variance in peak $\dot{V}O_2$ (33), the last 2 years have witnessed a plethora of publications using variants of the 20mSRT to estimate/predict the ratio-scaled peak $\dot{V}O_2$ of children and to relate their 20mSRT score to current and future health (2,23).

In a wide-ranging review, Tomkinson et al (53) acknowledge "gas-analyzed peak $\dot{V}O_2$" as the criterion measure of aerobic