

Aerobic fitness of children and adolescents

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Aerobic fitness may be defined as the ability to deliver oxygen to the muscles and to utilize it to generate energy during exercise. Aerobic fitness therefore depends upon the pulmonary, cardiovascular and haematological components of oxygen delivery and the oxidative mechanisms of the exercising muscle. Maximal oxygen uptake (VO_{2max}), the highest rate at which an individual can consume oxygen during exercise, is widely recognized as the best single measure of aerobic fitness.¹ However, although VO_{2max} limits the performance of aerobic exercise it does not describe fully all aspects of aerobic fitness.

Exercise of the intensity and duration required to elicit VO_{2max} is rarely experienced by many young people and typical bouts of physical activity are submaximal and of short duration.² Under these circumstances, it is the transient kinetics of VO_2 which best assesses the integrated response of the oxygen delivery system and the metabolic requirements of the exercising muscle. The time constant of the young person's VO_2 kinetic response to exercise is not related to VO_{2max} .³ Furthermore, VO_{2max} is neither the best measure of the ability to sustain submaximal exercise nor the most sensitive means of monitoring improvements in aerobic fitness with training. Despite its origins in anaerobic metabolism, blood lactate accumulation provides a valuable indicator of submaximal aerobic fitness and a means of detecting improvements in muscle oxidative capacity with training in the absence of changes in VO_{2max} .³ VO_{2max} is, however, the most widely documented measure of young people's aerobic fitness and I will focus on this variable.

Robinson⁴ published the first laboratory study of boys' VO_{2max} in 1938 and Astrand⁵ reported the VO_{2max} of both boys and girls in 1952, yet the assessment and interpretation of young people's VO_{2max} is still shrouded

with controversy. The conventional criterion for the attainment of VO_{2max} during an exercise test is a levelling-off or plateau in VO_2 despite an increase in exercise intensity, but over 50 years ago Astrand⁵ demonstrated that this response is not typical of the majority of children and adolescents. It has therefore become more common to use the term peak VO_2 , the highest VO_2 elicited during a progressive exercise test to exhaustion, to describe young people's aerobic fitness. If in a progressive exercise test the young participant exhibits clear symptoms of fatigue, supported by a heart rate

which is levelling off at about 200 beats·min⁻¹ and a respiratory exchange ratio > 1.0, a maximal effort can be assumed and peak VO_2 has been shown to reflect the limits of aerobic fitness.⁶ Peak VO_2 is a robust variable with a repeatability across three trials a week apart of about 4%, which compares very favourably with the repeatability of the assessment of adults' VO_{2max} .⁷

Peak VO_2 data are available for children as young as 3 years of age, but studies are difficult to interpret and often confounded by small sample sizes, an absence of objective exercise termination criteria, and a tendency to report only mass-related data. The database on 8-16 year-olds is more secure and cross-sectional data indicate an almost linear increase in boys' peak VO_2 (L·min⁻¹) in relation to age. Girls' data demonstrate a similar trend, but with a tendency to level off at about 14 years of age. Longitudinal studies are sparse, but generally reflect the cross-sectional findings. Boys' data show a gradual increase from 8 through and beyond 16 years with the largest annual increases occurring between 13 and 15 years of age. Girls' data are less consistent and peak VO_2 appears to progressively rise to 13 years and then level off from about 14 years of age. Boys exhibit higher peak VO_2 than girls from prepuberty and over the age range 8-16 years, boys' values increase by about 150% and girls' by about 80%.³

Peak VO_2 is highly correlated to body mass and researchers have conventionally 'controlled' for growth by simply dividing peak VO_2 by body mass and expressing it as the ratio millilitres of oxygen per kilogramme body

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mass per minute (ie mL·kg⁻¹·min⁻¹). When peak VO₂ is expressed in this manner, a different picture emerges from that apparent when absolute values of peak VO₂ (in L·min⁻¹) are used. In most studies boys' mass-related peak VO₂ has been reported to remain remarkably stable over the age range 8-16 years with values approximating 48-50 mL·kg⁻¹·min⁻¹, whereas girls' values generally fall with increasing age, from about 45-35 mL·kg⁻¹·min⁻¹. Boys show higher mass-related peak VO₂ than girls throughout childhood and adolescence, with the sex difference reinforced by girls' greater accumulation of body fat during puberty.

Ratio scaling, however, rather than removing the influence of body mass 'over-scales', favours light individuals and penalises heavier ones. This effect can be clearly demonstrated by correlating the ratio scaled variable (peak VO₂ in mL·kg⁻¹·min⁻¹) with the original body mass variable. If the scaling has removed the effect of body mass, the relationship between the two variables should not be significantly different from zero. Numerous studies have shown this not to be the case demonstrating unequivocally the failure of ratio scaling to produce a size-free variable.³

To examine the effect of scaling on the interpretation of peak VO₂ during growth and maturation, Welsman et al.⁸ used both ratio and allometric (log-linear analysis of covariance) scaling to remove the effects of body mass from peak VO₂ in children, adolescents and adults. In males, the conventional ratio analyses were consistent with the literature showing no significant differences between the age groups. In contrast, the allometric analyses revealed significant, progressive increases in peak VO₂ across groups, indicating that relative to body size, males' peak VO₂ increased during growth rather than remaining static. Females' ratio scaled peak VO₂ showed no change from prepuberty into circumpuberty, but a significant decrease from circumpuberty to adulthood whereas the allometrically scaled data demonstrated that females' peak VO₂ significantly increased into puberty with no subsequent decline into young adulthood.

The application of allometry to longitudinal data is complex, but multilevel modelling techniques enable body size, age and sex effects to be partitioned concurrently within an allometric framework. Armstrong & Welsman⁹ applied multilevel modelling to the interpretation of peak VO₂ in 11-17 year-olds and founded the analysis on 388 peak VO₂ determinations. They demonstrated a progressive increase in peak VO₂ with age in both sexes independent of body mass. The magnitude of the age-related increase was smaller in girls than boys with the difference between the sexes increasing with age. These data challenge the conventional view of peak VO₂ during growth, which has been founded on the use of ratio scaling.

As children grow they also mature and the physiological responses of adolescents should be considered in relation to biological as well as chronological age. Several studies have classified maturation according to the indices of pubic hair described by Tanner¹⁰ and reported peak VO₂ in ratio with body mass to be unrelated to maturation in both boys and girls.³ However, a study of 176 12 year-olds demonstrated that although peak VO₂ in ratio with body mass remained unchanged with stage of maturation, when body mass was appropriately controlled using allometry there was a significant, positive effect of maturation on peak VO₂ independent of body mass.¹¹ Similarly, when stages 2-5 for pubic hair development were introduced into the multilevel model of 11-17 year-olds' peak VO₂ described above a significant, positive and incremental effect of stage of maturation on peak VO₂ independent of age and body mass, was demonstrated in both sexes.⁹

The data described herein show that the interpretation of young people's aerobic fitness is confounded without appropriate consideration of age, growth and maturation. The use of ratio scaling to accommodate differences in body mass to make comparisons of aerobic fitness within or between studies is widespread, but data expressed in this manner must be treated with caution as the assumption that peak VO₂ increases in direct proportion with body mass is not tenable. Inappropriate methods of controlling for body mass have in fact clouded our understanding of aerobic fitness during growth and maturation.

The paper by Rodrigues et al.,¹² published in this issue provides, for the first time, rigorously-determined data on aspects of the aerobic fitness of Brazilian 10-14 year-olds. The valuable study by Rodrigues et al. will initiate further research into an important component of Brazilian youth's health and well-being. The objective of this editorial is to stimulate debate on the interpretation of the data and thereby further the understanding of children and adolescents' aerobic fitness.

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