Right: Participants undertaking a combined ramp and supramaximal exercise test to exhaustion to determine $\dot{V}O_{2max}$
Courtesy Zoe Saynor

The BASES Expert Statement on Measurement and Interpretation of Aerobic Fitness in Young People

Produced on behalf of the British Association of Sport and Exercise Sciences by Dr Alan Barker, Prof Craig Williams FBASES, Dr Keith Tolfrey FBASES, Dr Samantha Fawkner and Dr Gavin Sandercock.

Introduction

Aerobic fitness is routinely measured in young people[1] and typically consists of either a direct measurement or indirect estimation of maximal oxygen uptake ($\dot{V}O_{2max}$). Maximal oxygen uptake has been used to study:

1. Changes in aerobic fitness during growth and maturation
2. The efficacy of exercise training programmes
3. The impact of disease on aerobic capacity
4. The relationship between physical activity, fitness and health.

For the latter, The BASES Expert Statement on The Importance of Young People's Aerobic Fitness for Health advocated the use of indirect and direct measures of aerobic fitness to identify children most at risk of cardio-metabolic disease and in greatest need of support (Tolfrey *et al.*, 2012). Consequently, there is a strong rationale and interest in the sport and exercise science community to measure aerobic fitness in young people. However, the most appropriate methods to measure and interpret max in this population remain controversial. This statement will, therefore, provide an expert summary of the key issues and conclude with recommendations for researchers and practitioners.

Background and evidence

Can young people produce a valid $\dot{V}O_{2max}$ measurement?

As only ~ 10 to 60% of children and adolescents display a $\dot{V}O_2$ plateau during exhaustive exercise across a variety of protocols (e.g., step-incremental or ramp) and modalities (e.g., treadmill and cycling), it has become conventional to use the term 'peak' $\dot{V}O_2$ in this population (Armstrong & Welsman, 1994). Consequently, objective secondary criteria, based on attaining a predefined heart rate (e.g., 85% of age predicted maximum) and/or respiratory exchange ratio (e.g., RER ≥ 1.00), are routinely used to verify a 'maximal' response in young people. A recent study, however, has demonstrated that the use of secondary criteria results in the acceptance of a 'sub-maximal' peak $\dot{V}O_2$, representing only ~ 80 to 90% of the achieved peak $\dot{V}O_2$, and can falsely reject a 'true' $\dot{V}O_{2max}$ measurement in children (Barker *et al.*, 2011). The authors called for researchers and practitioners to abandon use of such secondary criteria and championed the use of a supra-maximal test following the initial incremental test to verify the measurement of a 'true' $\dot{V}O_{2max}$. In this study, the children performed a supra-maximal bout set at 105% of the peak power achieved during the incremental test after 15 min of rest. This protocol identified a valid $\dot{V}O_{2max}$ measurement in 12 out of 13 children, despite only observing a $\dot{V}O_2$ plateau in 4 children during the initial incremental test to exhaustion. These findings have since been replicated using cycling and treadmill based protocols in young people with cystic fibrosis, children with expiratory flow limitation and children with spina bifida, highlighting the broad application of the combined incremental and supramaximal test to produce a 'true' measurement of $\dot{V}O_{2max}$ in young people.

What is the most appropriate method to scale $\dot{V}O_{2max}$ for body size?

Absolute $\dot{V}O_{2max}$ (mL·min-1) is typically adjusted using the ratio standard method with body mass (kg) as the scaling variable (mL·kg-1·min-1). However, this approach has been criticised due to its failure to create a 'size-free' expression of $\dot{V}O_{2max}$ in young people as it favours lighter individuals (Armstrong & Welsman, 1994). Rather, allometric scaling may provide a more appropriate method to adjust $\dot{V}O_{2max}$ for body size.

Body mass is used typically to scale $\dot{V}O_{2max}$ for body size as it is simple to measure and shares a strong relationship with absolute $\dot{V}O_{2max}$. However, body mass does not account for differences in body composition and expressing $\dot{V}O_{2max}$ relative to an estimation of fat free mass (FFM) is more appropriate in young people. While an estimation of FFM may be achieved using age- and sex-specific algorithms to estimate body fat percentage from skinfold measures, techniques such as air displacement plethysmography or dual-energy X-ray absorptiometry are preferable. The latter is particularly useful, as it can partition out lower body FFM, which offers a slight advantage compared to total FFM when scaling $\dot{V}O_{2max}$ in young people (Graves *et al.*, 2013). Alternatively, a direct measure of the active muscle mass involved during exercise provides the most valid body size variable to adjust $\dot{V}O_{2max}$ (Tolfrey *et al.*, 2006), but requires access to sophisticated equipment such as a magnetic resonance imaging scanner.

Can a reliable and valid estimate of $\dot{V}O_{2max}$ be obtained from field-based measures?

The valid measurement of $\dot{V}O_{2max}$ in the laboratory setting requires expensive equipment and technical expertise, which may be impractical for use in large cohort studies. Field-based tests, which are relatively easy to administer in large groups, and require limited equipment, offer a practical alternative.

The 20-m shuttle run test (20-mSRT) is the most widely used field-based test to assess aerobic fitness in young people and UK centile data and health-related cut points are available (Sandercock *et al.*, 2012). As the test demands limited space, it can be conducted indoors, which controls for environmental conditions, and is not reliant on self-pacing strategies. A systematic review recently concluded the 20-mSRT to be the most reliable and valid field-based method to estimate aerobic fitness in young people (Castro-Pinero *et al.*, 2010). Performance in the 20-mSRT is typically expressed as laps, levels or distance completed. While published equations are available to estimate peak $\dot{V}O_2$ after accounting for factors such as the age, sex and size of the participant (e.g., Mahar *et al.*, 2011)[2], users must be aware of the error associated with the estimated peak $\dot{V}O_2$ (typically 4 to 6 mL·kg-1·min-1) when interpreting their data.

Some Local Authorities and the Association for Physical Education have cautioned against the use of the 20-mSRT in schools, due to health concerns with exercising children to exhaustion. However, the two largest UK-based studies (Liverpool SportsLinx and East of England Healthy Hearts Study) have completed circa 80,000 (35,000 of which are published) 20-mSRT assessments in 9 to 16 year olds and have yet to record a single adverse event. The 20-mSRT is also used routinely for the population-based assessment of aerobic fitness in 5 to 18 year olds across Europe, USA and Australasia.

Popular alternatives to the 20-mSRT are distance walk/run tests, such as the 1 or 0.5 miles tests. Although normative data and criterion referenced cut-offs for fitness are available (e.g., Zhu *et al.*, 2010), some children may have problems with pacing during these tests (e.g., starting too fast or slow) and the reliability and validity of the distance walk/run tests are lower than the 20-mSRT (Castro-Pinero *et al.*, 2010). Finally, sport-specific tests, such as the Yo-Yo intermittent running test, are also available to predict aerobic fitness but currently have limited supporting evidence in comparison to the 20-mSRT and distance walk/run tests in young people.

Recommendations

In the laboratory setting:

- A combined incremental and supramaximal exercise test protocol should be used to obtain a valid measurement of $\dot{V}O_{2max}$ in young people both in health and disease
- Secondary criteria (e.g., heart rate and RER thresholds) should not be used to verify the attainment of $\dot{V}O_{2max}$ in young people as they result in a 'sub-maximal' peak $\dot{V}O_2$
- Allometric scaling procedures should be used to scale $\dot{V}O_{2max}$ for body size provided sufficient data are available to derive a sample specific scaling factor. However, as normative data or thresholds for health are currently only available in the ratio standard format it may be prudent to express $\dot{V}O_{2max}$ using both methods
- As body mass does not account for differences in body composition, $\dot{V}O_{2max}$ should be adjusted for using FFM in young people
- In the research setting, direct quantification of the muscle mass recruited during exercise should be used to adjust $\dot{V}O_{2max}$ for body size as this offers an advantage compared to total FFM.

In the field setting:

- The 20-mSRT is currently the method of choice to provide a safe, reliable and valid estimate of $\dot{V}O_{2max}$ in the field setting, and UK reference data are readily available
- Performance in the 20-mSRT should be expressed as laps, levels of distance completed, as the prediction of peak $\dot{V}O_2$ using the test data is associated with error
- If the 20-mSRT cannot be undertaken, distance walk/run tests are a suitable popular alternative but have poorer reliability and validity in young people. ■

1 The term 'young people' in this expert statement refers to children and adolescents aged < 18 years.

2 The 20m-SRT estimates peak $\dot{V}O_2$ as, despite eliciting a maximal effort, the achievement of $\dot{V}O_{2max}$ was not verified appropriately in the majority of these studies.

words:

Dr Alan Barker

Alan is a Lecturer at the University of Exeter and Programme Director of the MSc in Paediatric Exercise and Health.

Dr Craig Williams FBASES

Craig is a Professor at the University of Exeter and Director of the Children's Health and Exercise Research Centre.

Dr Keith Tolfrey FBASES

Keith is a Reader at Loughborough University and Chair of the BASES Division of Physical Activity for Health.

Dr Samantha Fawkner

Samantha is a Senior Lecturer at the University of Edinburgh and Section Editor for the Journal of Sports Sciences.

Dr Gavin Sandercock

Gavin is a Senior Lecturer at the University of Essex and Chief Investigator for The East of England Healthy Heart Study.

References:

Armstrong, N. & Welsman, J.R. (1994). Assessment and Interpretation of Aerobic Fitness in Children and Adolescents. Exercise and Sport Science Reviews, 22, 435-476.

Barker, A.R., Williams, C.A., Jones, A.M. & Armstrong, N. (2011). Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. British Journal of Sports Medicine, 45, 498-503.

Castro-Pinero, J. *et al.* (2010). Criterion-related validity of field-based fitness tests in youth: a systematic review. British Journal of Sports Medicine, 44, 934-943.

Graves, L.E. *et al.* (2013). Scaling of peak oxygen uptake in children: A comparison of 3 body size index models. Medicine and Science in Sports and Exercise, doi:10.1249/MSS.0b013e31829bfa79.

Mahar, M.T., Guerieri, A.M., Hanna, M.S. & Kemble, C.D. (2011). Estimation of aerobic fitness from 20-m multistage shuttle run test performance. American Journal of Preventive Medicine, 41, S117-123.

Sandercock, G. *et al.* (2012). Centile curves and normative values for the twenty metre shuttle-run test in English schoolchildren. Journal of Sports Sciences, 30, 679-687.

Tolfrey, K. *et al.* (2006). Scaling of maximal oxygen uptake by lower leg muscle volume in boys and men. Journal of Applied Physiology, 100, 1851-1856.

Tolfrey, K., De Ste Croix, M., Stratton, G. & Williams, C.A. (2012). The BASES expert statement on the importance of young people's aerobic fitness for health. The Sport and Exercise Scientist, 31, 16-17.

Zhu, W., Plowman, S.A. & Park, Y. (2010). A primer-test centered equating method for setting cut-off scores. Research Quarterly for Exercise and Sport, 81, 400-409.