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Fact and Fiction in Youth Cardiorespiratory Fitness

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Abstract: Cardiorespiratory fitness (CRF) 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. Peak oxygen uptake ($\dot{V}O_2$) is internationally recognized as the criterion measure of youth CRF. It is well-documented that in youth peak $\dot{V}O_2$ increases with sex-specific, concurrent changes in a range of age- and maturity status-driven morphological and physiological covariates with the timing and tempo of changes specific to individuals. However, a recent resurgence of interest in predicting peak $\dot{V}O_2$ from field test performances and the persistence of fallacious interpretations of peak $\dot{V}O_2$ in 1:1 ratio with body mass have obfuscated general understanding of the development of CRF. Moreover, as spurious relationships arise when ratio-scaled data are correlated with health-related variables the use of this scaling technique has confounded the relationship of youth CRF with indicators of current and future health. This paper reviews the extant evidence and concludes that the interpretation of youth CRF and the promotion of young people's health and well-being should be founded on scientific facts and not on fictions based on flawed methodology and specious interpretation of data.

Key Words: Adolescents; children; clinical red flags; health and well-being; peak oxygen uptake; 20 metre shuttle run

Neil Armstrong is Professor of Paediatric Physiology at the University of Exeter where he has been awarded PhD and DSc degrees. He has received honorary doctorates from Universities in both Europe and North America for his research in developmental physiology and the promotion of children's health. He Chairs the European Group of Pediatric Work Physiology and serves as a core member of the IOC expert group on sport and health in youth. Neil has authored/edited 17 books and over 600 peer-reviewed publications on pediatric physiology. He has been invited to present his research in 45 countries and with Dr Jo Welsman won the only Queen's Anniversary Prize (QAP) for Higher Education to be awarded for research in sport and exercise medicine. The QAP was presented by HM Queen Elizabeth at Buckingham Palace for *'World class work which is of outstanding quality and importance to the nation'*.

Jo Welsman completed her PhD at the University of Exeter before appointment as Senior Research Fellow in the Children's Health and Exercise Research Centre. Her research interests focus on how physiological data collected during exercise should be interpreted in relation to changes in body size and composition during growth and maturation. She has co-authored/edited 3 books with Neil Armstrong and is a regular international commentator on and prolific writer of peer-reviewed papers on the use of allometric analyses of cross-sectional data and the application of multilevel log-linear regression modelling for longitudinal data sets.

1. Introduction

Aerobic or cardiorespiratory fitness (CRF) 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. Rigorously determined peak oxygen uptake ($\dot{V}O_2$) is internationally recognized as the 'gold standard' measure of youth CRF and its development in childhood and adolescence is well-documented [1]. Understanding CRF has, however, been clouded by expressing and analysing youth peak $\dot{V}O_2$ in 1:1 ratio with body mass. Erroneous analyses have been compounded by a resurgence of interest in predictions of peak $\dot{V}O_2$ from field performance tests, particularly the 20 metre shuttle run test (20mSRT) [2,3]. Taken together ratio scaling with body mass and predictions of peak $\dot{V}O_2$ from 20mSRTs have misrepresented youth CRF, misinterpreted the development of CRF, obscured understanding of putative relationships between CRF and health, misled clinical practice, and promoted injudicious recommendations for health promotion. This paper outlines the evidence-based development of youth CRF, reveals the fallacy of ratio scaling, refutes the validity of the 20mSRT as a measure of peak $\dot{V}O_2$, and exposes the limitations and potential ramifications of the use of health-related cut-points or 'clinical red flags' with children and adolescents.

2. Development of cardiorespiratory fitness

Peak $\dot{V}O_2$ increases with sex-specific, concurrent changes in a range of age- and maturity status-driven morphological and physiological covariates with the timing and tempo of changes specific to individuals [4]. Peak $\dot{V}O_2$ is often expressed in relation to chronological age but it is simplistic to describe it in this manner and age-related CRF 'norms' make little sense [5]. Boys' peak $\dot{V}O_2$ values are higher than those of girls, at least from late childhood, and the sex difference increases as they progress through adolescence reaching ~40% in post-pubertal 18 year-olds [6]. The small pre-pubertal sex difference (~10%) in peak $\dot{V}O_2$ can be largely attributed to boys' greater stroke volume [7] but sex differences in maximal arterio-venous oxygen difference have also been reported [8]. Boys' marked increase in age- and maturity status-driven muscle mass accounts for most of the progressive sexual divergence in peak $\dot{V}O_2$ in puberty [4]. Boys' peak $\dot{V}O_2$ may be supplemented further by a sex-specific increase in haemoglobin concentration in the late teens enhancing boys' oxygen-carrying capacity but this has yet to be empirically demonstrated in longitudinal studies [9]. (See reference 1 for a comprehensive review of the evidence).

3. Cardiorespiratory fitness and ratio scaling

That there is neither a rigorous scientific rationale nor a statistical justification for applying ratio scaling of youth peak $\dot{V}O_2$ with body mass (i.e. interpreting it in $mL \cdot kg^{-1} \cdot min^{-1}$) was clearly demonstrated by Tanner [10] 70 years ago and elucidated theoretically in numerous subsequent tutorial papers [11]. Quite simply valid application of a ratio standard assumes an underlying set of specific statistical assumptions which are rarely met (see reference 12 for a comprehensive discussion). Recent cross-sectional [12] and longitudinal [4] analyses of ~2,500 determinations of the peak $\dot{V}O_2$ of 10-18 year-olds have demonstrated empirically and unequivocally that ratio scaling of peak $\dot{V}O_2$ with body mass is fallacious. Ratio scaling favours lighter (e.g. clinically underweight or delayed maturing) and penalizes heavier (e.g. overweight or advanced maturing) youth. Moreover, spurious relationships arise when ratio-scaled data are correlated with other health-related variables and use of this scaling technique has confounded understanding of the development of youth CRF [13] and its relationship with indicators of current and future health [14]. A topical example is correlating cardiovascular risk factors in overweight/obese youth with ratio-scaled peak $\dot{V}O_2$ where any association is more likely to reflect overweight/obese status than CRF and misinterpret true relationships between CRF and indicators of cardiovascular health [15].

4. Cardiorespiratory fitness and the 20 metre shuttle run test

20mSRT performance is not a measure of CRF but a function of willingness and ability to run between two lines 20 m apart while keeping pace with audio signals which require the running speed to increase each minute until the participant is unable or unwilling to continue. The number of shuttles (or stages) completed are converted into an estimate of peak $\dot{V}O_2$ through a prediction equation.

The limitations of predicting peak $\dot{V}O_2$ from 20mSRT scores were revealed in a recent meta-analysis where it was demonstrated that with children over 50% of correlation coefficients between 20mSRT scores and peak $\dot{V}O_2$ explain less than half the shared variance with peak $\dot{V}O_2$. It was reported that the criterion-related validity of the 20mSRT with children was only *'moderate'* and the meta-analysis concluded that, *'testers must be aware that the performance score of the 20mMSR test is simply estimation and not a direct measure of cardiorespiratory fitness'* [16]. The low criterion-related validity of the 20mSRT is better illustrated by the 95% range for a true peak $\dot{V}O_2$ value estimated from 20mSRT performance being ~10 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ or ~24% [17]. Similarly, the very poor reliability of the test is reflected by 95% confidence intervals of ±2.5 stages on a test lasting 4 to 6 stages [18].

Huge gender differences in 20m SRT performance scores are regularly reported with differences in teenagers as high as 95-100% [19]. This is more than double the sex differences recorded in laboratory measures of peak $\dot{V}O_2$ and probably reflects the unwillingness of teenage girls in some cultures to exercise publicly to exhaustion.

Unsound methodology misleads interpretations of youth CRF and a noteworthy example is the claim founded on 20mSRT performance scores that there has been, *'a substantial decline in CRF since 1981, which is suggestive of a meaningful decline in population health'* [20]. As is well-documented [21] and resolved in the International Olympic Committee Consensus Statement on health and fitness of young people [22] there is no compelling scientific evidence to suggest that youth CRF has declined over time. In explanation of the alleged decline in CRF supporters of the 20mSRT have asserted that, *'direct analysis of the causal fitness-fatness connection indicates that increases in fatness explain 35-70% of the declines in CRF'* [20]. In the real world there is no *'causal fitness-fatness connection'* as fat mass does not influence CRF [23]. Being fat is different from being unfit but carrying extra fat mass (dead weight) over a series of shuttle runs increases the individual's workload and inevitably lowers their 20m SRT performance score. This fatal misinterpretation is compounded by 20mSRT prediction equations estimating peak $\dot{V}O_2$ in direct ratio with body mass (i.e. in $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and therefore including fat mass in the denominator – a double penalty for overfat children.

Despite flawed methodology, specious interpretation of performance scores, and fallacious scaling of data, 20mSRT performance scores have been used to estimate peak $\dot{V}O_2$ and produce international CRF 'norms' [24], 'reference standards for preschool children' as young as 2 years [25], and international records of which country has the fittest children? [26]. Recent studies have proposed predictions of CRF from 20mSRT performance to survey and monitor international health and fitness [27], to determine metabolic and cardiovascular risk [28], to evaluate physical activity interventions [29], and to identify children who warrant medical intervention to improve their current and future health – the raising of 'clinical red flags' [30].

5. Cardiorespiratory fitness and 'clinical red flags'

A very serious concern to us is how the 20mSRT has stimulated the use of 'clinical red flags' to identify '*children and adolescents who may benefit from primary and secondary cardiovascular prevention programming'* [30]. These 'clinical red flags' founded on predictions of peak $\dot{V}O_2$ from 20mSRTs classify 8-18 year-olds on the basis of a single sex-specific 'cut-point' and specify that values of peak $\dot{V}O_2$ below 42 and 35 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ raise concern among males and females, respectively [30]. It is astonishing to us as scientists that single fixed values of peak $\dot{V}O_2$ based on a methodology in which the 95% range for predicting a true peak $\dot{V}O_2$ value is ~10 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ are advocated as health-related cut-points. Even when rigorously determined and analyzed it is, at best, naïve to interpret CRF in this manner as CRF develops in accord with sex-specific, age- and maturity status-driven concurrent changes in a range of morphological and physiological covariates not just body mass [1, 4, 13]. A single estimated peak $\dot{V}O_2$ in ratio with body mass as a 'clinical red flag' for pre-pubertal, pubertal, and post-pubertal young people cannot be justified. Youth who raise a 'clinical red flag' are more likely to be suffering from what Tanner referred to as, *'no more formidable a disease than statistical artefact'* [10].

6. Conclusion

Many of the studies based on 20mSRT performance scores stem from a genuine desire to promote youth health and we wholeheartedly support the intention but the assessment and interpretation of young people's CRF in relation to present and future health must be founded on scientific rigour. The estimation/prediction of CRF from the 20mSRT is untenable, the interpretation of performance scores as predicted peak $\dot{V}O_2$ in ratio with body mass is fallacious, and the extrapolation of these defective data to 'clinical red flags' and similar health-related cut points is indefensible. Interpretation of youth CRF and promotion of youth health and well-being should be founded on scientific facts and not on fictions based on flawed methodology and specious interpretation of data.

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