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Response to the comment by Armstrong and Welsman on 'Developing a New Curvilinear Allometric Model to Improve the Fit and Validity of the 20-m Shuttle Run Test as a Predictor of Cardiorespiratory Fitness in Adults and Youth'

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We welcome the opportunity to respond to Armstrong and Welsman's comment on our recent paper '*Developing a New Curvilinear Allometric Model to Improve the Fit and Validity of the 20-m Shuttle Run Test as a Predictor of Cardiorespiratory Fitness in Adults and Youth'*. [1]

All sport, exercise and health-related scientists/researchers agree that cardiorespiratory fitness (CRF) is a well-established and robust indicator of cardiovascular health, as well as a valuable predictor of all-cause mortality. They also agree that CRF can be accurately assessed by the direct measurement of maximal oxygen uptake ($\dot{V}O_{2peak}$) in youth or ($\dot{V}O_{2max}$) in adults. $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$ are commonly regarded as *the* "gold standard" criterion measure of CRF recorded in the units ($mL.kg^{-1}.min^{-1}$), recognising that $\dot{V}O_{2peak}$ (or $\dot{V}O_{2max}$) must be divided by the entire body mass to best reflect CRF [1,2,3]. Recently, Welsman and Armstrong [4] have attempted to allometrically scale or adjust $\dot{V}O_{2peak}$ for differences in body mass (M) using some undisclosed function of M to explore the relationship between $\dot{V}O_{2peak}$ and 20-metre shuttle run test (20mSRT) speed. They found that the relationship between $\dot{V}O_{2peak}$ and 20mSRT speed was not significant, except for when the entire body-mass related $\dot{V}O_{2peak}$ ($mL.kg^{-1}.min^{-1}$) was adopted as the criterion measure, in which case the association between 20mSRT speed and $\dot{V}$O2peak became significant[4], a fact that makes the rationale for Welsman and Armstrong's current letter redundant.

Despite its importance, direct measurements of $\dot{V}O_{2max}$ in epidemiological or population studies are rare — primarily due to feasibility issues related to the time to administer the test and the lack of having $\dot{V}O_{2max}$ routinely measured in clinical practice. Therefore, estimating or predicting CRF (*i.e.*, $\dot{V}O_{2max}$ recorded in $mL.kg^{-1}.min^{-1}$) has emerged as an attractive alternative. In the scientific literature, this process of developing a prediction model is commonly referred to as establishing the predictive or criterion validity of either a new test (e.g.,the Harvard Step Test, the Cooper 12-minute run test and of course the 20mSRT), and/or another set of relevant predictor variables (e.g., body mass, age, sex, physical activity and body fat).

Various models to predict $\dot{V}O_{2max}$ ($mL.kg^{-1}.min^{-1}$) using additive linear equations have been published recently, some include estimates of physical activity (Nes *et al*., [5]) while others do not (Myers *et al*., [6], Menezes-Junior et al., [7]. However, Nevill and Cook [8] highlight a number of

concerns with these linear, additive models. The models suggest linear associations with all key predictors such as age, body mass and/or BMI. However, there is strong evidence, certainly from the findings reported by Myers *et al*. [6] and Nevill et al. [9, 10, 11], that curvature exists suggesting that one or more of these associations is likely to be non-linear. The current paper [1], to which Armstrong and Welsman have chosen to comment upon; not only has addressed all these key issues when predicting $\dot{V}O_{2max}$ (mL.kg^{-1}.min^{-1}) but has also incorporated the 20mSRT (speed, km.h^{-1}) as an additional predictor.

It would appear that the introduction of the 20mSRT, in addition to all the other predictor variables (age, height, mass, sex) has triggered their concern. Such concern~~s~~ ~~are~~ is unfounded. We are simply using 20mSRT speed (km h^{-1}) as one of a number of predictor variables to improve the fit when predicting $\dot{V}O_{2max}$ (mL.kg^{-1}.min^{-1}). The 20mSRT speed is merely one of a number of variables entered into the saturated log-linear regression model and refined using backward elimination, to produce the parsimonious allometric solution/model to confirm the "criterion" validity of the model when predicting $\dot{V}O_{2max}$ (mL.kg^{-1}.min^{-1}), as reported in our paper. The resulting allometric solution/model also provides an additional valuable new insight, that being the oxygen cost of the final shuttle running speed appears to increase in a non-linear, J-shaped curve, a finding that is both biologically and physiologically plausible and interpretable. This new insight provides additional evidence of "construct" validity. Hence, not only does the article by Nevill et al. [1] provide overwhelming evidence of criterion validity (the cross-validation R^2= 71.9%, with a CV= 9.6% and a 95% LoA 0.73 ± 8.3 ml.kg^{-1}.min^{-1}), it also provides supportive evidence of "construct" validity, a new insight that has been unavailable until now.

Finally, in their commentary, Armstrong and Welsman promote lab-based, gas-analyzed measurement of $\dot{V}O_{2peak}$ as synonymous with CRF, yet $\dot{V}O_{2peak}$ alone does not describe all aspects of CRF (e.g., fractional utilization of oxygen, mechanical efficiency), both of which the 20mSRT theoretically capture. They also criticize the 20mSRT as a procedure/test "founded on the willingness and capability of a child or adolescent to transport their body mass (including fat mass) between two lines 20-m apart while keeping pace with audio signals". They should recognize that directly-measured $\dot{V}O_{2peak}$ is also affected by psychosocial factors (*e.g.,* motivation, self-efficacy) and also

provides an indication of a child's willingness to exercise maximally, something that they appear to overlook and/or fail to acknowledge..

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