CHAPTER NUMBER (to be completed by Editor)

ESTABLISHING MAXIMAL OXYGEN UPTAKE IN YOUNG PEOPLE DURING A RAMP CYCLE TEST TO EXHAUSTION

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1.1 INTODUCTION

Maximum oxygen uptake ($VO_{2\,max}$) is recognized as the best single measure of aerobic fitness, although the most appropriate methods to assess and interpret VO_{2max} in young people remain controversial (Armstrong and Welsman 1994). As only ~ 20-40% of children performing exercise to exhaustion display a plateau in their VO_2 response to exercise (Armstrong et al. 1995; Rowland 1993), the term 'peak VO_2' (VO_{2peak}) has been adopted. Consequently, paediatric researchers rely on subjective indicators of intense effort (e.g. facial flushing, sweating, unsteady gait, hyperpnoea) supported by secondary 'objective' criteria (e.g. respiratory exchange ratio [RER], blood lactate and heart rate values) to verify a 'maximal' response.

A ramp based cycling protocol is becoming a popular method for determining VO_{2max} both in healthy and diseased children (e.g. Barker et al. 2008; Stevens et al. 2009). However, it remains to be established whether the highest VO_2 attained during ramp cycling exercise reflects a 'true' VO_{2max}, as determined from supra-maximal exercise testing. Moreover, a recent study has questioned the validity of using secondary criteria during ramp exercise, as RER, heart rate and blood lactate criteria can underestimate $VO_{2\,max}$ by 30-40%, or falsely reject a valid $VO_{2\,max}$ measure (Poole et al. 2008). As large inter-individual variations in RER (0.95-1.15), heart rate (185-215 beats·min^{-1}) and blood lactate (3-12 mM) are present in children at $VO_{2\,max}$ (Armstrong and Welsman 1994), it is plausible that the utility of secondary criteria are equally inappropriate in young people.

The aims of this study were to test the following hypotheses: 1) that using secondary criteria can result in the acceptance of a 'sub-maximal' VO_{2max} during ramp cycling exercise in children; and 2) that the highest VO_2 recorded during a ramp

cycling exercise in children is comparable to the highest VO_2 achieved during supra-maximal testing, thus satisfying the plateau requirement for a 'true' VO_{2max}.

1.2 METHODS

1.2.1 Experimental Design

Thirteen 9-10 y old children (8 boys, 5 girls) completed two tests to exhaustion within a single day on an electronically braked cycle ergometer (Lode, Groningen, Netherlands). The first test consisted of a ramp exercise test to exhaustion to determine their VO_2 max using a ramp rate of 10 $W \cdot min^{-1}$. Following a recovery period consisting of 10 min cycling at 10 W and 5 min rest, the participants completed a supra-maximal bout to exhaustion with the intensity set to 105% of the peak power achieved during the ramp test. Oxygen uptake (EX671, Morgan Medical, Kent, UK) was determined every 15 s and a finger tip capillary blood was analysed for lactate concentration following the ramp test (YSI 2300, Yellow Springs, Ohio, USA).

1.2.2 Criteria for establishing VO_2 max

A plateau in the VO_2 profile during the ramp test was identified by examining the profile of the residuals against a linear regression extrapolated from the 'linear' portion of the response to end exercise. The secondary criteria used to verify a 'maximal' VO_2 were an RER of 1.00, a heart rate of 195 $beats \cdot min^{-1}$ and within 85% of age predicted maximum (220-age), and a blood lactate concentration of $\geq$ 6 mM (Armstrong and Welsman 1994; Dencker et al. 2007; Leger 1996; Rowland 1993).

1.2.3 Statistical analysis

Boys' and girls' data were grouped (n=13) to form a single data set for analysis. Paired samples t-tests examined mean differences between outcome variables with the Bonferroni correction applied for multiple comparisons. Limits of agreement analyses were used to establish the mean bias and 95% confidence limits between the ramp and supra-maximal test responses. The alpha level was set at 0.05.

1.3 RESULTS

Four participants had a VO_2 plateau at exhaustion, whereas seven showed a linear and two showed an accelerated response. At exhaustion the mean RER was 1.11 [SD 0.06, range 0.99-1.20]. A single boy failed to reach the RER criterion. In the 12 participants that satisfied this criterion, the VO_2 recorded at an RER of 1.00 (1.293 $L \cdot min^{-1}$ [SD 0.265]) significantly underestimated the VO_2 recorded at exhaustion (1.681 $L \cdot min^{-1}$ [SD 0.295], P=0.002), representing 77% of the latter.

Mean heart rate at exhaustion was 202 $beats \cdot min^{-1}$ [SD 7, range 191-214]. All children satisfied the 85% of their age predicted maximum criterion (equivalent to ~ 179 $beats \cdot min^{-1}$). Three children failed to reach the 195 $beats \cdot min^{-1}$ criterion, despite a clear plateau in VO_2 at exhaustion in 2 of these participants. In the participants that satisfied the heart rate criteria, the VO_2 recorded at 85% of their age predicted maximum (1.345 $L \cdot min^{-1}$ [SD 0.228]) and at 195 $beats \cdot min^{-1}$ (1.556 $L \cdot min^{-1}$ [0.265]) significantly underestimated the VO_2 recorded at exhaustion (1.690 $L \cdot min^{-1}$ [SD 0.284] and 1.721 [SD 0.318] respectively; P<0.002), representing 80% and 90% of the latter.

Mean blood lactate following ramp exercise was 6.7 mM [SD 2.1, range 4.2-12.1]. Six children (4 boys, 2 girls) satisfied the blood lactate criterion of ≥ 6 mM. Of the 7 participants who had a blood lactate < 6 mM, 2 had a plateau in their VO_2 profile.

Supra-maximal testing yielded a $VO_{2\ peak}$ that was not significantly different from the ramp test (1.615 $L \cdot min^{-1}$ [SD 0.307] vs. 1.690 $L \cdot min^{-1}$ [SD 0.284], P=0.090, respectively), despite exercising at a higher power output (127 vs. 120 W). The limits of agreement for the $VO_{2\ peak}$ achieved during supra-maximal and ramp exercise found a mean bias of -0.075 $L \cdot min^{-1}$, which corresponds to ~ 4% of the initial ramp test $VO_{2\ peak}$ score (95% confidence limits: -0.263 to 0.112 $L \cdot min^{-1}$ or -16 to 6%).

1.4 CONCLUSION

The main findings from the current study are that during ramp cycling exercise in a group of healthy 9-10 year old children: 1) a plateau in the VO_2 profile at exhaustion is an infrequent phenomenon, occurring in ~ 30% of children; 2) adherence to commonly used secondary criteria to validate a maximal effort in young people can result in either a 'sub-maximal' $VO_{2\ max}$ or a rejection of a participant's $VO_{2\ max}$ score despite a plateau being evident; and 3) supra-maximal testing at 105% of the power output achieved during ramp exercise did not increase the $VO_{2\ peak}$ achieved compared to the ramp test, thus suggesting the achievement of a 'true' $VO_{2\ max}$ during the initial ramp test.

Collectively these results provide a basis for paediatric researchers to abandon the use of secondary criteria to validate a 'maximal' VO_2. Rather, as supra-maximal testing elicits a $VO_{2\ peak}$ similar to the ramp protocol, thus satisfying the plateau criterion despite only been present in 30% of the initial ramp responses, it is recommended that the use of such tests should be adopted as *the* appropriate method of confirming a 'true' $VO_{2\ max}$ in healthy young people.

1.5 NOTE

At the time of writing the full version of this paper is *in press* in the *British Journal of Sports Medicine*, but published on-line (doi:10.1136/bjsm.2009.063180), and this extended abstract is reproduced here with permission from the BMJ Publishing Group.

1.6 REFERENCES

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