Perceived Exertion: Recent Advances and Novel Applications in Children and Adults

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Since 2008, there have been significant advances to assess the efficacy of the ratings of perceived exertion (RPE) to predict maximal oxygen uptake or estimate the time to volitional exhaustion in adults. The principle of using the relationship of submaximal RPE values with the performance criterion of interest has also been applied successfully to estimate maximal strength in adults and children. This short note describes how these studies have further confirmed the predictive efficacy of the RPE. Potential studies which may enhance our understanding of perceived exertion in children are also described. [*J Exerc Sci Fit* • Vol 7 • No 2 (Suppl) • S11–S17 • 2009]

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Introduction

The following review provides an update to an earlier paper by Faulkner and Eston (2008), the content of which formed the basis for a keynote lecture with the above title at the 2009 Society of Chinese Scholars on Exercise Physiology and Fitness Annual Conference in Hong Kong. Since 2008, there have been significant advances to assess the efficacy of the ratings of perceived exertion (RPE) to predict maximal oxygen uptake or estimate the time to volitional exhaustion in adults (Coquart et al. 2009a, 2009b; Lambrick et al. 2009; Morris et al. 2009). The same principle of using the relationship of submaximal RPE values with the performance criterion of interest has also been applied successfully to estimate maximal strength in adults (Eston & Evans 2009) and children (Robertson et al. 2008). This short note describes how these studies have further confirmed the predictive efficacy of the RPE. Potential studies which may enhance our understanding of perceived exertion in children are also described.

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Prediction of $\dot{V}O_{2peak}$ from RPE in Obese Women

Following recommendations to test the efficacy of using the RPE to predict $\dot{V}O_{2max}$ in clinical populations (Davies et al. 2008; Faulkner et al. 2007; Eston et al. 2006), Coquart et al. (2009b) tested whether submaximal RPE could be applied successfully with obese women. In their study, 43 obese women performed a graded exercise test (GXT) on cycle ergometer until volitional exhaustion. The initial work rate was set at 10 W for 1 minute and then incremented by 10 W · min^{-1} until volitional exhaustion. Using similar procedures to Faulkner and Eston (2007), individual linear regressions between $\dot{V}O_2$ and RPE 15 were extrapolated to RPE 20 in order to predict $\dot{V}O_{2peak}$. Actual and predicted $\dot{V}O_{2peak}$ were not significantly different (13.9 ± 3.0 *vs.* 14.2 ± 3.3 mL · kg^{-1} · min^{-1}, respectively). The Pearson product moment correlation between actual and predicted $\dot{V}O_{2peak}$ was high ($r = 0.82$). The 95% limits of agreement analysis on these values were also noteworthy (bias ± 1.96 standard deviations, 0.3 ± 3.7 mL · kg^{-1} · min^{-1}). Their results confirmed that the principle of using the individual RPE:work rate ($\dot{V}O_2$) relationships up to and including

RPE 15 elicited during a submaximal GXT can be used to predict $\dot{V}O_{2peak}$ in obese women, thereby obviating the necessity of performing a GXT to voluntary exhaustion in such groups.

RPE 13 Predicts $\dot{V}O_{2max}$ During a Continuous, Ramp Exercise Test

Lambrick et al. (2009) assessed the utility of a single, continuous exercise protocol to estimate maximal oxygen uptake from submaximal heart rate (HR) and the RPE in healthy, low-fit women during cycle ergometry. Although the sample size was small, and therefore inferences from such data should be interpreted with caution, the results nevertheless showed that a single, short and continuously ramped exercise test provided remarkably accurate estimates of maximal oxygen uptake.

The rationale for their study was based on the observation that previous studies to predict $\dot{V}O_{2max}$ from the RPE (Eston et al. 2008, 2006, 2005; Faulkner & Eston 2007; Faulkner et al. 2007) involved incremented (continuous or intermittent) 2–4-minute stages of exercise. Estimation and perceptually-regulated tests using the aforementioned protocols are therefore quite time-consuming and therefore relatively expensive to run. Following previous observations by Faulkner et al. (2009) that $\dot{V}O_{2max}$ could be predicted fairly accurately from a single estimation trial, up to and including an RPE 13 in healthy, low-fit men and women, Lambrick et al. (2009) postulated that a single, short and continuously ramped estimation test which excluded the higher exercise intensity ranges (> RPE 17) would be more practically advantageous and feasible in a clinical environment. Such a test would require less exertion and motivational effort from the exerciser and would be more comfortable and safer.

In this regard, it is worth noting the results from the study on sedentary women by Rose and Parfitt (2008). They observed that mean (± SD) RPEs of 11.4 (± 1.2) and 12.0 (± 1.2) corresponded to positive affective states determined as "good" (+ 3) and "fairly good" (+ 1), respectively, when these ratings of affect (*Feeling Scale*, Hardy & Rejeski 1989) were used as the independent variable to regulate exercise intensity. The evidence therefore suggests that RPE tends to be positive up to an RPE 13, but then starts to decline beyond an RPE 13 (Sheppard & Parfitt 2008; Ekkekakis et al. 2004) as exercise intensity increases beyond the ventilatory threshold. An exercise test that requires exercise up to and including RPE 13 would therefore be more acceptable to healthy, low-fit groups who may be negatively affected by the demand of high intensity exercise (Parfitt et al. 1996; Hardy & Rejeski 1989).

Lambrick et al. (2009) believed that a ramp protocol, whereby workload increases at a continual rate until the attainment of $\dot{V}O_{2max}$, would enable the rate of change in the RPE to be more closely monitored and reach an intensity equivalent to an RPE 13 (somewhat hard) in a relatively shorter period of time compared to a 3-minute step-incremented exercise test. In their study, 11 women performed a continuous and ramped incremental exercise (1 W · 4 s^{-1}) to volitional exhaustion to measure $\dot{V}O_{2max}$. For each individual, the gaseous exchange threshold was determined retrospectively. The RPE and HR values recorded prior to and including RPE 13 and gaseous exchange threshold were extrapolated against corresponding oxygen uptake to the theoretical maximal RPE (20) and peak RPE (19), and age-predicted maximal HR, respectively, to predict $\dot{V}O_{2max}$. They observed no significant differences between measured (30.9 ± 6.5 mL · kg^{-1} · min^{-1}) and predicted $\dot{V}O_{2max}$ from all six methods, although the limits of agreement were narrowest and reliability was highest for predictions of $\dot{V}O_{2max}$ from RPE 13 to RPE 19, which corresponded to terminal RPE (19.1 ± 0.9). They also showed that prediction of $\dot{V}O_{2max}$ from a regression equation using submaximal HR and work rate (W) at an RPE 13 was also not significantly different to actual $\dot{V}O_{2max}$ ($R^2 = 0.78$, standard error of estimate [SEE] = 3.4 mL · kg^{-1} · min^{-1}).

The data from the study of Lambrick et al. (2009) provides additional evidence that the RPE may be a valuable tool that can be easily employed as an adjunct to HR, and may provide supplementary clinical information that is superior to using HR alone. A continuous submaximal ramp protocol has the advantage of reducing the duration of the test, and the associated cost and motivational effort involved in an exercise stress test. Further study using this procedure is highly recommended.

The Case for Randomized Work Rates for Predicting Maximal Functional Capacity

Randomized perceptually-regulated exercise test protocol

On the basis that recommendations from previous research to assess the efficacy of perceptually-regulated exercise tests (PRETs) to predict $\dot{V}O_{2max}$ are confounded by the various methodologies (4–5-minute intermittent incremental bouts, Eston et al. 2008, 2005; 2- and 4-minute continuous incremental bouts, Eston et al. 2006; 3-minute continuous incremental bouts, Faulkner et al. 2007), Morris et al. (2009) modified the original methodologies of Eston and colleagues. In their study, 23 men and women (31 ± 9.9 years) completed four counter-balanced PRETs separated by 48 hours. These comprised two separate sessions involving 2-minute perceptually-regulated bouts and two sessions involving 3-minute perceptually-regulated bouts on a cycle ergometer. A notable difference between their study and the studies of Eston and colleagues is the use of a *randomized* PRET at self-regulated intensities of RPE 9, 11, 13, 15 and 17. As in the studies by Eston and colleagues, $\dot{V}O_2$ values for RPE ranges 9–13, 9–15 and 9–17 were extrapolated to RPE 20 using regression analysis to predict individual $\dot{V}O_{2max}$ scores.

The study of Morris et al. (2009) provides further convincing evidence for the efficacy of predicting maximal aerobic capacity from PRETs, particularly as this was also observed using a protocol of *randomized perceptually-regulated bouts*! The strength of this design is that the participant will not have had the benefit from immediate memory of an easier preceding work rate at each successive bout, making it more difficult to plan or set successive work rates according to a known order of perceptual regulation (i.e. 9, 11, 13, 15, 17) and equal stepwise RPE increments of 2. A further advantage to such an approach is the likely avoidance of cardiorespiratory and muscle fatigue in the latter stages of a continuous exercise test, which has been documented previously by Coquart et al. (2009a, see following section). It is also noteworthy from the study by Morris et al. (2009) that predictions of $\dot{V}O_{2max}$ from the second trial were more reliable than those from the first trial for both the 2- and 3-minute PRET protocols, further confirming a practice effect (Eston et al. 2008, 2006, 2005; Buckley et al. 2000). However, the average $\dot{V}O_{2max}$ value predicted from the 2-minute protocol for both 9–13 and 9–15 RPE:$\dot{V}O_2$ ranges significantly underestimated the measured $\dot{V}O_{2max}$ value by 4 and 3 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. The discordance of this finding in comparison to the study of Eston et al. (2006), who observed that predictions from 2-minute continuous incremental bouts were more accurate than corresponding predictions from 4-minute bouts, is most likely attributable to the protocol used. In the study by Eston et al. (2006), participants were allowed up to 3 minutes to habituate to the perceptually-regulated bout to ensure that the work rate equated to the prescribed RPE. This period, in addition to an already warmed-up state, may have allowed steady state oxygen consumption to be achieved sooner.

Randomized work rates, RPE and estimated time to end task

On the basis of their observations that RPE varies considerably at a given percentage of time to exhaustion in participants performing at the same constant work rate (Garcin et al. 1998), Garcin et al. (1999) proposed that the RPE could be associated with a second scale based on the subjective estimation of exhaustion time (the *Estimated Time Limit* scale; ETL). The ETL scale provides further information on the psychological load (intensity and duration) of exercise (Garcin & Billat 2001; Garcin et al. 1999) and allows for a subjective estimation of time that can be maintained at any intensity and at any given instant (Coquart et al. 2009a). The ETL scale has been shown to be a valid and reliable perceptual tool (Coquart & Garcin 2007; Garcin et al. 2003, 1999). The RPE and ETL scales complement one another as the RPE is concerned with the subject's current status (how hard the exercise currently feels) and the ETL assesses how long the individual thinks he/she can continue at the current exercise level until exhaustion.

Whilst recognizing that the RPE from incremental exercise tests could be used to predict maximal oxygen uptake, Coquart et al. (2009a) hypothesized that the accuracy of this prediction could be improved as the RPE could be affected by the fatigue generated from the first stages of the incremental test. They postulated that if for the same workload, the RPEs are slightly higher during a submaximal incremental test, in comparison with a test using randomized workloads, the maximal oxygen uptake predicted by the relationship between oxygen uptake and RPE could be underestimated. As a consequence, any training intensity prescription based on RPE or ETL from the incremental exercise test would be lower and the training effect might therefore also be lower than expected. If this was the case, they believed it would be preferable to use the RPE or ETL obtained during a discontinuous test with constant workloads.

Coquart et al. (2009a) therefore examined the influence of successive bouts of fatiguing exercise on perceptual and physiological markers during an incremental exercise test. Twenty-seven experienced competitive male cyclists performed a continuous incremental and discontinuous exercise test with randomized work rates. The continuous test commenced at 150 W for 4 minutes and increased by 50 W every 4 minutes until 300 W, after which the work rate was incremented by 25 W · 2 min^{-1} until volitional exhaustion. The stages were successive and sustained over a long duration (i.e. 4 minutes) in order to induce fatigue. For the discontinuous test, the same work rates were used, although these were applied in random order.

They showed that the successive workloads during the continuous incremental test generated higher fatigue as the HR, breathing frequency, minute ventilation and blood lactate concentration were higher in the latter stages of the test, in comparison to the randomized procedure. However, the values for RPE and ETL were not significantly different between the two exercise test conditions. As there was no difference between the perceptual responses, they suggested that when the order of workloads was not known, the cyclists mainly focused on internal signals to evaluate their perception of effort, whereas they focused less on internal signals when they anticipated the next stages. They concluded that perceptually based values measured during both tests may be used equally to predict maximal oxygen uptake and to regulate exercise intensity. However, they noted that there are advantages to using perceptually based values from an exercise test with randomized workloads as this may avoid an accumulation of fatigue.

Using the RPE to Predict the 1-Repetition Maximum

An interesting development in the last 2 years has been the use of submaximal RPE to predict strength in young healthy men and women (Eston & Evans 2009) and children (Robertson et al. 2008). Defined as the capacity of a defined muscle or muscle group to exert force against a resistance in a single maximum effort (Horvat et al. 2003), the 1-repetition maximum (1-RM) test is commonly used to assess strength. Percentages of an individual's 1-RM are often used by instructors, coaches and physicians to calculate and prescribe intensity for resistance training (Pereira & Gomes 2003; Lesuer et al. 1997). However, despite its universal application, the safety of a 1-RM protocol has been questioned as individuals new to maximal load-bearing activity may incur high stress with the risk of muscular injury or cardiovascular event (Niewiadomski et al. 2008; Braith et al. 1993). The direct assessment of a 1-RM is also time-consuming and impractical for large groups (Niewiadomski et al. 2008; Nascimento et al. 2007; Brzycki 1993). Such limitations have led to the development of prediction models that typically employ measures of performance (i.e. repetitions to fatigue) and/or anthropometric (i.e. body mass) factors (Materko et al. 2007; Horvat et al. 2003; Cummings & Finn 1998; Lesuer et al. 1997). A unique feature of the following studies is the use of RPEs to predict the 1-RM.

Prediction of the 1-RM from RPE in young active men and women

Eston and Evans (2009) assessed the validity of using submaximal RPEs to predict 1-RM in young adults, using the Borg 6–20 RPE Scale (Borg 1998). In their study, 20 healthy and active sports science students completed two trials involving resistance exercises for both the upper and lower body. In the first trial, the 1-RM for the bilateral biceps curl and the bilateral knee extension was determined for each participant. In the second trial, participants performed one set of 2 repetitions at each %1-RM intensity equivalent to 20%, 40% and 60% of 1-RM for both knee extension and biceps curl exercises. The order of the loads across the three sets was randomized and the participants were blindfolded so that the sight of the weight could not influence the RPE! The RPE was recorded immediately after two repetitions had been completed at each intensity. Individual RPEs recorded at each of the three intensities were subjected to linear regression analysis and the line of best fit was extrapolated to RPE 20 to predict 1-RM in both exercises.

Eston and Evans (2009) observed no significant difference between the 1-RM predicted from RPE 20 and measured 1-RM for both exercises for the men and women. Measured and predicted values for men were, respectively, 46.0 ± 4.6 kg and 45.2 ± 6.1 kg for biceps curl, and 46.3 ± 3.8 kg and 43.0 ± 7.1 kg for knee extension. Measured and predicted values for women were, respectively, 18.6 ± 5.7 kg and 19.3 ± 5.6 kg for biceps curl, and 25.5 ± 9.6 kg and 27.2 ± 12.6 kg for knee extension. Pearson product-moment correlation coefficients between actual and predicted 1-RM for the biceps curl and knee extension were 0.97 and 0.92, respectively. These results provide evidence that submaximal RPEs can be used to provide reasonably accurate, safe and time-saving estimates of 1-RM in young and active men and women. The method provides proof of principle that submaximal exercise intensities in the range of 20–60% of the 1-RM can be used to estimate the 1-RM for upper and lower body exercise.

It remains to be determined if the use of alternative %1-RM combinations (smaller increments in resistance) or whether practice in repeated submaximal perceptual estimation sessions with sufficient intermittent recovery periods, would lead to greater accuracy in the prediction of 1-RM, although I believe it would. Further research to test these assumptions and assess the efficacy of using perceived exertion to predict the 1-RM in other populations is recommended.

Prediction of the 1-RM from RPE in children

To facilitate testing large numbers of children in short time periods, Robertson et al. (2008) developed various regression equations using the RPE to estimate the 1-RM for the biceps curl and knee extension in children. In their study, the 1-RM was determined in 70 children (35 girls, 35 boys) aged 10–14 years. The children then performed two sets of 10 repetitions of the biceps curl and knee extension exercise using weights approximating 30% and 50% 1-RM. The RPE was assessed during the final repetition of each set using the children's *OMNI Resistance Exercise Scale*. Sex-specific regression equations were developed to predict 1-RM using RPEs derived from both sets of biceps curl and knee extension exercises. For both girls and boys, the RPE ranged from 3.7 to 6.6 for the biceps curl and 4.1 to 7.2 for knee extension. The 1-RM prediction equations were as follows.

Girls

Biceps curl 1-RM = 15.0 − (0.472 × RPE-ARM @2.3 kg) − (0.973 × RPE-ARM @3.6 kg); $R^2 = 0.76$, SEE 1.14 kg

Knee extension 1-RM = 39.75 − (1.891 × RPE-LEG @3.4 kg) − (2.397 × RPE-LEG @6.8 kg); $R^2 = 0.79$, SEE 2.82 kg

Boys

Biceps curl 1-RM = 22.25 − (0.383 × RPE-ARM @2.7 kg) − (1.758 × RPE-ARM @4.6 kg); $R^2 = 0.79$, SEE 1.37 kg

Knee extension 1-RM = 39.66 − (3.316 × RPE-LEG @4.6 kg) − (1.571 × RPE-LEG @ 8.0 kg); $R^2 = 0.76$, SEE 3.23 kg

Further Considerations for Studies on RPE with Children

Perceived exertion involves the interplay of afferent feedback from cardiorespiratory, metabolic and thermal stimuli and efferent feed-forward mechanisms to enable an individual to evaluate how *hard* or *easy* an exercise task feels. However, it is moderated by psychological factors (e.g. cognition, memory and understanding of the task), and situational factors (e.g. knowledge of duration and temporal characteristics of the task). It is therefore evident that assessment of how accurately a child can rate perceived exertion (RPE), or use the RPE to perceptually regulate intensity, remains a significant challenge. The following section describes some of these challenges and considerations for how they may be addressed. Additional detail on the following is contained in a recently published editorial (Eston 2009).

When a child suddenly stops during an exercise test with little advance notice, one may assume that this is commensurate with a sudden rapid rise in RPE. However, the sudden cessation of exercise may frequently result in failure to record a maximal RPE. It is not uncommon for studies to report less than the theoretical maximal RPE in adults (e.g. Faulkner et al. 2007), so it should perhaps be no surprise to observe the same phenomena in children (e.g. Eston et al. 2009; Barkley & Roemmich 2008). However, it is important to note that when a child is asked to rate his/her perceived exertion, it assumes an understanding and memory of what it feels like to exercise to a state of maximal exhaustion. Young children may never have experienced this state and have no understanding of how it feels. The use of a memory-recall strategy to facilitate understanding of perceived exertion is therefore problematic as it relies on past experience and the cognitive maturational level of the child. Nevertheless, it has been observed that following several practice sessions, children as young as 7 years of age become quite skilled in their understanding of the RPE, to the extent that they can reliably produce a given intensity for a prescribed RPE (Parfitt et al. 2007; Eston et al. 2000) when an appropriate child-specific scale is used.

It remains to be determined if the nature of the picture on the RPE scale is critically important to the child's understanding and appreciation of what is required when he/she is asked to provide an RPE or use an RPE to regulate intensity. For example, during performance of a cycling task, how important is it that the pictures on the RPE scale be of a child cycling? Would it make any difference if the pictures were of a child running? Observations from studies in children between 7 and 10 years of age which used scales that are not pictorially-congruent with the task indicate that the pictures appear to have had no effect on the children's ability to use the scale to rate intensity

(Eston et al. 2009) or to perceptually regulate intensity (Parfitt et al. 2007). It is not possible to say for certain that the "mode-congruence" of scales is an important issue in children of this age, but from the evidence to date, it is doubtful that it makes a difference. It may even be the case that no figures are needed as the children do not focus on the figures when they are exercising, but on the numbers or a given proportion of the line or curve which they are able to conceptually appreciate. This issue has yet to be explored in young children, but I believe this area of investigation is warranted for future studies before further mode-specific pictorial scales are proposed.

In this regard, a number of pictorial RPE scales have been introduced and validated (for reviews see: Coquart et al. 2009c; Lamb et al. 2008; Eston & Parfitt 2006; Eston & Lamb 2000). One of the limitations with the literature in this area is the lack of studies focusing on specific age ranges. Studies have frequently included broad age ranges of children (e.g. 8–12 years), which includes children at very different stages of cognitive and physical maturation (Groslambert & Mahon 2006), and mean that data from such studies should therefore be interpreted with caution.

Whatever strategy is used to help the child appreciate the concept of perceived exertion, it is highly probable that the ability to rate the intensity level will be affected by the extent to which the fundamentals of *time*, *distance* or the requirements of the task are understood and appreciated by the child. A lack of understanding of these factors may influence the RPE and the selection of work rate according to a given RPE. If there is understanding of these factors, it is likely that exercise intensity will be quite different for a known or anticipated duration of the task being 10 seconds or 10 minutes. However, would the work rate be different in tasks where anticipated times to complete the task are 5 minutes and 15 minutes? To date, no studies have explored the effects of *anticipated time* on task in children, but it would seem plausible to hypothesize that this would be moderated by age, experience and the cognitive ability to judge and assimilate the pacing of the task according to the time or distance required or anticipated.

In a similar manner, it is plausible to assume that the perceived exertion response is moderated by the methodological characteristics of incremental exercise tests—whether they are intermittent (with passive or active recovery), continuous or randomized, and also whether the bouts are long (~3 minutes) or short (~1 minute). As children's activity patterns are rarely consistent for 1–3-minute periods, and rarely continuous in nature, this is an important point.

It is highly likely that the efficacy of predicting maximal functional capacity from estimation procedures or from perceptually-regulated bouts would also be affected by age, cognitive ability and the duration of exercise bouts. Future research could explore the efficacy of the RPE or the ETL in this regard. Similarly, it would be of interest to see if the differences in the rate of change in the RPE under various conditions during self-paced or constant-load tasks to exhaustion is proportional to the time remaining on the task, as observed in some studies in adults (Crewe et al. 2008; Faulkner et al. 2008; Joseph et al. 2008; Eston et al. 2007; Horstman et al. 1979). Studies to explore this phenomenon have yet to be conducted with children.

All the above considerations will be influenced by the child population in question. One might expect that athletes, who have greater experience of maximal or near-maximal levels of exertion, may possess a more robust perceptual framework of the exercise intensity range and a greater appreciation of the importance of pacing for tasks of varying durations. One might also expect that the RPE response and the methods by which the RPE response is evaluated would be affected in children with learning difficulties. Such children may have difficulty in interpreting numerical scales alone and may benefit more from well-drawn, mode-congruent scales with a more limited number range.

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