PERCEIVED EXERTION RESEARCH IN THE 21ST CENTURY: DEVELOPMENTS, REFLECTIONS AND QUESTIONS FOR THE FUTURE

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The ratings of perceived exertion are a widely accepted measure of quantifying, monitoring and regulating exercise intensity. A critical review of the perceived exertion literature since 2000 provides a useful insight into the concepts and themes that have featured prominently in the literature. In this regard, five main themes of enquiry concerning perceived exertion have emerged. These include child-specific rating scales, pictorial scales for adults, self-regulation and the efficacy of using the RPE for predicting maximal oxygen uptake, observations that the RPE scales with time or distance remaining in open- and closed-loop exercise tasks, and the influence of carbohydrate and caffeine ingestion on the ratings of perceived exertion. We provide a critical review of these developments and reflect on their relative contributions to knowledge, their potential practical applications and the questions which remain for future research on perceived exertion in adults and children.

Keywords: CERT, OMNI, perceived exertion, perceptually-regulated exercise, teleoanticipation

Introduction

Perceived exertion may be defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise (Robertson & Noble 1997). Monitoring how we feel about the exercise we are performing is a continuous process for active humans. The psychological interpretation of the cardiorespiratory, metabolic and musculoskeletal mediators of exertion plays an important role in the setting and regulation of exercise intensity and compliance to exercise participation.

In the early 1960s, Gunnar Borg developed the 6–20 Rating of Perceived Exertion (RPE) scale. This scale has been widely applied as a valuable, reliable, and easily understood means of quantifying, monitoring and evaluating the exercise tolerance and magnitude of exertion in healthy adult populations and other groups (American College of Sports Medicine [ACSM] 2006; Borg 1998). The relationship between perceived exertion and human performance has been an area of considerable scientific and clinical interest over the last 50 years and has become a focus of extensive research in the exercise and sport sciences. The purpose of this paper is not to review the fundamental principles and historic development of the ratings of perceived exertion, as described in previously published review articles (Hampson et al. 2001; Watt & Grove 1993; Williams & Eston 1989; Carton & Rhodes 1985) and books (Borg 1998; Noble & Robertson 1996), but to evaluate the recent findings and landmark steps that have emerged since 2000.

In the last 8 years, more than 200 scientific publications have used the ratings of perceived exertion as a psychophysical marker of the intensity of the exercise response. For the purposes of this review paper, we focus on five main developments in the study and application of the ratings of perceived exertion in the last 8–10 years. These include the development and assessment of child-specific rating scales, the development
Development of Children’s Perceived Exertion Rating Scales

There have been important advances in the study of effort perception in children in the last decade and these have been described more fully elsewhere (Lamb et al. 2009; Eston & Parfitt 2006). Despite early attempts to improve a child’s conceptual understanding of the well-known Borg 6–20 RPE scale through the addition of pictorial descriptors (Nystad et al. 1989), it was deduced that difficulties in using the Borg scale to estimate and produce exercise effort was most likely attributed to a child’s cognitive ability. The validity and usefulness of an RPE scale for children is dependent on age, reading ability, experience and conceptual understanding. The latter is a developmental issue, which has been the subject of an excellent review by Groslambert and Mahon (2006).

The suggestion by Eston and colleagues (Williams et al. 1991) that a 1–10 scale would be more appropriate for children led to the significant development of the Children’s Effort Rating Table (CERT; Eston et al. 1994; Williams et al. 1994). The CERT is a 1–10 scale that uses verbal anchors which are more familiar to children than the Borg 6–20 RPE scale and verbal expressions chosen by children as descriptors of exercise effort. The CERT has international appeal. Leung et al. (2002) assessed the validity and reliability of a Chinese-translated (Cantonese) version of the CERT (Figure 1). The correlations between the CERT and power output, heart rate and oxygen uptake were consistently higher than those for the 6–20 RPE Scale. They also reported higher reliability (intraclass correlations, ICC) for the CERT (ICC = 0.96 cf. 0.89) derived from two continuous, incremental cycling tests.

These studies served to reinforce the importance of a more meaningful child-specific scale for promoting a better understanding of the child’s ability to rate how hard or easy the exercise was perceived to be. The CERT initiative for a simplified scale containing more “developmentally-appropriate” numerical and verbal expressions led to the development of scales which incorporated simplified numerical, verbal and pictorial descriptors of perceived exertion. These scales generally depict four to five animated figures, portraying increased states of physical exertion. Like the CERT, the scales have embraced a similar, condensed numerical range and words or expressions which are either identical to (Pictorial-CERT, Yelling et al. 2002), abridged from (Bug and Bag Effort [BABE] Scale, Parfitt et al. 2007; Cart and Load Effort Rating [CALER] Scale, Eston et al. 2000) or similar in context to the CERT (OMNI, Robertson et al. 2000; Robertson 1997).

The CALER Scale (Eston et al. 2000) depicts a child pulling a cart along a flat terrain which is progressively laden with bricks. In the study by Eston et al. (2000), 20 children aged 7–10 years performed four intermittent incremental effort production tests at CALER 2, 5 and 8, for 5 minutes at each intensity, over a 4-week period. An increase in power output across trials (44 W, 65 W and 79 W at CALER 2, 5 and 8, respectively) confirmed that the children understood the scale. Furthermore, the study demonstrated strong evidence that practice improved the reliability of effort perception in children of this age with narrower limits of agreement and higher intraclass correlations between the later trials. More recently, in a study to provide an independent assessment of the validity of the CALER and OMNI Scales, Barkley and Roemmich (2008) observed that the CALER had similar validity to the OMNI scale in that both scales displayed a strong, positive, linear relationship with heart rate and oxygen uptake during cycle ergometry with boys and girls aged 9–10 years ($r = -0.92$ and $r = -0.88$, respectively).

The BABE Scale portrays a Disney-like animation of an ant performing a stepping exercise onto a bench wearing a backpack of increasing load. Parfitt et al. (2007) evaluated the validity and reliability of the CALER and the
BABE rating scales in 30 boys and girls aged 7–11 years for intra- and intermodal regulation of effort production in a triple-repeated, randomized, intermittent production paradigm. When the scales were used as the independent variable to regulate exercise intensity at ratings of 3, 5 and 8, highly significant differences (p < 0.001) in heart rate were observed, with overall mean values of 155 ± 16, 167 ± 16 and 177 ± 15 beats min⁻¹, respectively. In addition, there was high intraclass reliability (ICC) for heart rate for the second and third trials for cycling (ICC = 0.81 and 0.90) and stepping exercise (ICC = 0.85 and 0.87) for the CALER and BABE scales, respectively.

These data provided good evidence that the BABE and CALER scales are valid and reliable measures of exertion and that the scales could be used interchangeably—the CALER scale may be used for regulating the intensity of stepping exercise and the BABE scale may be used for regulating the intensity of cycling exercise. A significant question posed from this study was which aspect of the scale (the picture, the location of the picture or the magnitude of the number) the child focused upon during the perceptually-regulated tasks as the work rate for stepping guided by CALER and cycling guided by BABE were similar! This may bring into question the need for mode-specific pictorial RPE scales in children.

The PCERT (Yelling et al. 2002) depicts a child ascending a 45-degree flight of steps at five stages of exertion, corresponding to CERT ratings of 2, 4, 6, 8 and 10. The PCERT has a strong linear relationship with minute ventilation, heart rate and oxygen uptake (r = 0.61–0.88) in children aged 10–11 years (Marinov et al. 2008). Roemmich et al. (2006) also reported correlations of 0.89 and 0.90 for oxygen uptake and heart rate, respectively, in 11-year-old children. These findings supported previous research which showed that perceived exertion simultaneously increased with exercise intensity and heart rate during estimation and production procedures (Yelling et al. 2002). Yelling et al. (2002) concluded that children could discriminate between four different exercise intensities and perceptually-regulate their exercise intensity according to four prescribed ratings from the PCERT (3, 5, 7 and 9).

The OMNI Scale, first proposed in 1997 (Robertson, 1997), has been extensively validated. It was originally employed to use pictorial interfaced cognitive anchoring procedures that would eliminate the need for mode-specific rating scales. However, since the initial OMNI validation study (Robertson et al. 2000), a number of mode-specific pictorial scales have been validated for various modes of exercise in children, including cycling (Barkley & Roemmich 2008; Robertson et al. 2000), walking/running (Robertson et al. 2006; Utter et al. 2002a), stepping (Robertson et al. 2005b) and resistance exercise (Robertson et al. 2008, 2005a). In the seminal OMNI validation study described by Robertson et al. (2000), four equal groups of 20 healthy African-American and white boys and girls aged 8–12 years performed a continuous, incremental exercise test on a cycle ergometer (25 W, 50 W, 75 W, 100 W). The authors reported similarly high positive linear associations between heart rate, oxygen uptake and perceived exertion for each gender and race cohort of children (r = 0.85–0.94). The study demonstrated that differentiated OMNI RPE for the legs was higher than either the chest RPE or overall RPE values. Barkley and Roemmich (2008) also reported increases in OMNI scores with parallel increases in heart rate and oxygen uptake during a progressively increasing exercise test on a cycle ergometer.

Submaximal ratings of perceived exertion from the OMNI resistance exercise scale have also been used to estimate one repetition maximum (1 RM) muscular strength with 10–14-year-old boys and girls (Robertson et al. 2008). Following two sets (10 repetitions) of biceps curl and knee extension exercise using weights equating to approximately 30% and 50% of 1 RM, the authors concluded that the OMNI resistance scale was a practical and accurate means of estimating 1 RM, and one which may be used when assessing large numbers of children in short time periods.

Roemmich et al. (2006) assessed the concurrent validity (cf. heart rate and oxygen uptake) and construct validity (cf. OMNI) of the PCERT in 11-year-old children. Validity of both the PCERT and OMNI scales was established for submaximal exercise. Although the PCERT and OMNI scores are not interchangeable because they have different scales, they reported that children assign similar percentages of the maximal scores on the scales for a given exercise intensity. Their study provides the first independent assessment of the validity of the PCERT and OMNI scales. Another pictorial rating scale has been based on the Borg 6–20 RPE scale, the RPE-C (Groslambert et al. 2000). This scale depicts a character in various stages of exertion ascending a vertical numerical scale. Groslambert et al. (2000) observed significant correlations between the RPE and heart rate for 5–6-year-old children, adolescents and adults (R² = 0.61, 0.72 and 0.94, respectively).

All the pictorial scales considered above have used either a horizontal line or one that has a linear slope, to express the relationship between a child’s perception of exertion and increasing exercise intensity. The Eston
and Parfitt (EP 2006) curvilinear scale utilizes a similar range of numbers and verbal anchors abridged from the CERT, but depicts a character at various stages of exertion on a concave slope with a progressively increasing gradient at the higher intensities. In the original version of the EP Scale, the area under the gradient was also filled by progressively darker shades of red (Figure 2).

Eston and Parfitt (2006) reported the EP Scale to have inherently obvious face validity. It acts on the basic assumption that children would readily conceive that the steeper the hill, the harder it is to ascend (Eston & Lamb 2000).

For the initial development of this scale, 20 children aged 8–11 years were requested to place a sitting figure and four ambulatory figures on a progressively increasing gradient. The figures were stylized to represent different stages of exertion and the children located them according to where they perceived they should be on the gradient. The children were then requested to self-regulate exercise intensities at RPE levels of 2, 5 and 8. On six separate occasions, separated by at least 1 and no more than 2 weeks, the children were requested to bench step for 3 minutes at an exercise intensity corresponding to RPEs of 2, 5 and 8, in that order, without reference to objective feedback measures. The protocol was continuous. ICCs of heart rates collected in the last 15 seconds of each 3-minute bout revealed good potential for the reliability of repeat effort productions across the six trials with values of 0.71, 0.75 and 0.76 for RPEs of 2, 5 and 8, respectively (Eston & Parfitt 2006).

A recent study on 15 boys and girls aged 7–8 years concurs with the postulation that the use of a pictorial scale which depicts a curvilinear gradient may be more appropriate for use with children (Lambrick et al. 2008). In their study, children performed an intermittent incremental exercise test (10 W min^-1) on a cycle ergometer to exhaustion. The children estimated their RPE using the EP Scale as described by Eston and Parfitt (2006), and also placed an unlimited number of marbles (out of a possible 50) into a separate jar to indicate their perceived exertion. There were highly significant increases in oxygen uptake, heart rate, ventilation and RPE from the EP Scale and the marbles task with increasing work rate. To test the curvilinear properties of the EP Scale and the marble task, linear and curvilinear analyses were conducted on the perceptual data in relation to work rate. Slightly higher $R^2$ values were reported for the curvilinear compared to the linear relationships between the perceptual data and work rate, for the EP Scale ($R^2 = 0.94$ and 0.93) and marbles task ($R^2 = 0.94$ and 0.80; $p < 0.01$), respectively. Such findings may be indicative of a curvilinear perceived exertion response in children in relation to linear increases in work rate.

![Fig. 2 The Eston-Parfitt (2006) perceived exertion scale.](image-url)
Support for the concept of depicting perceived exertion through a curvilinear pictorial scale is also evident from a most recent study, which provided an independent assessment of the validity of the CALER and OMNI Scales (Barkley & Roemmich 2008). In their study, 16 boys and girls aged 9–10 years performed a progressive exercise test on a cycle ergometer to exhaustion. It was observed that the proportions of the maximal CALER (75%) and maximal OMNI (74%) scales were significantly less than the peak percentage of the predicted maximal heart rate (95%). The authors reported that although both scales appear to illustrate effort during submaximal exercise successfully, the scales might benefit from modifications to the upper range. They suggested that a change in the linearity of the scales so that the final stages increase at a greater rate or increase in a curvilinear fashion could improve the agreement with physiological measures at peak exercise intensities.

**Adult OMNI Scales of Perceived Exertion**

Since the seminal validation study of the OMNI Scale (Robertson et al. 2000), the original OMNI has branched out considerably. Numerous variants of the OMNI scale now encompass a wide range of diverse activities for boys and girls, and men and women. Adult versions of the OMNI scales of perceived exertion have been assessed for cycle ergometry (Mielke et al. 2008; Utter et al. 2006; Robertson et al. 2004; Kang et al. 2003), walking and running (Irving et al. 2006; Utter et al. 2004; Kang et al. 2003) and resistance exercise (Duncan et al. 2006; Lagally & Robertson 2006; Robertson et al. 2003). In adults particularly, an established theme has been to assess the construct validity of the Adult-OMNI scales of exertion with the Borg 6–20 RPE scale.

These groups have overwhelmingly observed a strong, positive, linear relationship between the Adult-OMNI scales of exertion and the Borg 6–20 RPE scale. Similar observations have been established during resistance exercise (Duncan et al. 2006; Lagally & Robertson 2006; Robertson et al. 2003). Lagally and Robertson (2006) reported high validity coefficients of \( r > 0.94 \) for men and women when the Adult-OMNI resistance scale was compared against the Borg 6–20 RPE scale. As expected, active muscle and overall body RPE reported through the Adult-OMNI during a dynamic leg extension exercise at 30%, 60% and 90% of the 1 RM increased with exercise intensity (Duncan et al. 2006). They reported that the Adult-OMNI resistance scale of exertion could be used to regulate resistance training intensity. Furthermore, research has provided concurrent validation of the Adult-OMNI-resistance scale when measuring RPE of the active and overall body in young recreationally trained females (18–30 years) and weight-trained males when performing upper- and lower-body exercise (Robertson et al. 2003).

It is noteworthy that in each of the studies which assessed construct validity (Irving et al. 2006; Lagally & Robertson 2006; Utter et al. 2006, 2004; Robertson et al. 2004) the “gold standard” criterion measure to which the Adult-OMNI scales were compared to was that of the classic traditional Borg 6–20 RPE scale. As high correlations have been observed between the Borg 6–20 RPE scale and the various Adult-OMNI scales (e.g., walking, running, cycling, stepping and resistance exercise), such research has confirmed that the Borg 6–20 RPE scale is...
an excellent tool to monitor, prescribe and regulate appropriate exercise intensities, regardless of the exercise modality in adults.

Although there has been a tremendous increase in Adult-OMNI validity studies published in the last 4 years, we remain puzzled and concerned about the scientific merit of the Adult-OMNI scales of perceived exertion and the need for more studies on its validity. The propagation of various pictorial forms of the Adult-OMNI to depict a given exercise mode for normal, healthy, able and literate adults lacks a convincing rationale. A persuasive argument or case for the Adult-OMNI scale and a convincing line of reasoning for duplicating the scale in so many pictorial forms has yet to be made. The various validity studies confirm that the Borg 6–20 RPE scale, a picture-less numerical scale which has stood the test of time for almost 50 years for assessing perceived exertion in adults, does not need to be replaced. We believe that a more useful and logical line of study for pictorial perceived exertion scales would be to assess their utility in cognitively-impaired individuals, who may more easily comprehend a simplified and illustrated perceptual scale.

Self-regulation and Prediction of Maximal Oxygen Uptake Using the RPE

An estimation-production procedure is considered to be an appropriate method to regulate exercise intensity as it resembles the prescription process that is typically applied in a practical setting (Noble & Robertson 1996). Historically, the procedure involves prescribing a rating of perceived exertion to a given heart rate, oxygen uptake or blood lactate value (production mode) reported from a prior graded exercise test (estimation mode). An alternative application of the estimation-production procedure has been proposed and tested by Eston et al. (2008, 2006, 2005) and Faulkner et al. (2007a). The authors were interested in identifying whether a graded exercise test that uses a range of submaximal effort production levels may provide an appropriate means of prescribing exercise intensity, providing that such an application led to an accurate prediction of the maximal oxygen uptake (VO₂max). Evidence suggests that the RPE elicited from estimation procedures can provide predictions of VO₂max or maximal work capacity that are as good as, or better than heart rate (Faulkner & Eston 2007; Eston et al. 1987; Noble et al. 1981; Morgan & Borg 1976).

Using a repeat-production procedure (Eston et al. 2008, 2006, 2005; Faulkner et al. 2007a), high- and low-active participants exercised at perceptually-regulated intensities prescribed at specific submaximal RPE (9, 11, 13, 15, 17) for either, 2, 3 or 4 minutes. In each exercise test, the order of the RPE was the same as it was felt that this approach was conceptually appropriate as it would resemble the approximate increases in exercise intensity during a graded exercise test. Eston et al. (2008, 2006, 2005) and Faulkner et al. (2007a) found no significant differences between measured VO₂max from a graded exercise test to volitional exhaustion, and VO₂max predicted from submaximal, perceptually-guided graded exercise tests (Figure 3).

In their first study (Eston et al. 2005), high-fit (active) men cycled at the five perceptually-regulated intensities according to the Borg 6–20 RPE scale, for 3 minutes at each intensity, in that order, on three separate occasions. Predictions of VO₂max were more accurate when extrapolating to maximal RPE (20) from five (RPE 9–17), rather than from four (RPE 11–17, 9–15) perceptual intensities. Similar findings were observed in their second study. Eston et al. (2006) demonstrated that a submaximal, perceptually-guided, graded exercise protocol (2 or 4 minutes), particularly of a 2-minute duration, provides acceptable estimates of maximal oxygen uptake from the same self-regulated RPE intensities. The observation that gender and aerobic fitness did not moderate the predictions of VO₂max was supported by Faulkner et al. (2007a). In their study, the predictions of VO₂max were typically more accurate when extrapolating to the peak RPE attained in the graded exercise test to volitional exhaustion (i.e. RPE 19 not 20), from five (RPE 9–17) rather than four (9–15) or three (9–13) perceptual intensities, regardless of gender or participants’ activity status (high-fit, low-fit). The findings that low-fit men and women were able to accurately perceptually-regulate their exercise intensity and provide...
acceptable estimates of VO$_{2\max}$ were also supported by Eston et al. (2008), who reported similar results with young to middle-aged sedentary men. In each of the studies, estimates of VO$_{2\max}$ were improved following practice, as demonstrated by the presence of smaller 95% limits of agreement (LoA) for the second and third trials, and increased between-trial correlation coefficients between the estimated and measured VO$_{2\max}$.

A further important observation from the studies by Eston et al. (2008) and Faulkner et al. (2007a) was that the prescribed changes in RPE were successful in eliciting step changes in exercise intensity and metabolic cost of 1–2 METS (3.5–7.0 mL·kg$^{-1}$·min$^{-1}$) in the sedentary or low-fitness groups. This is commensurate with standard submaximal graded exercise tests for healthy individuals (ACSM 2006).

Using a slightly alternative approach on 49 men and women of high- and low-fitness, Faulkner and Eston (2007) demonstrated accurate predictions of VO$_{2\max}$ when extrapolating submaximal VO$_2$ values using RPE ranges of 9–13, 9–15 and 9–17 during an estimation-based cycle ergometry test. In their study, the most accurate predictions of VO$_{2\max}$ were from whole-body perceptions of exertion. Peripheral perceptions of exertion significantly underestimated the measured VO$_{2\max}$. Using an estimation procedure, recent research has also demonstrated accurate predictions of VO$_{2\max}$ from submaximal VO$_2$ values elicited during a simulated multistage fitness test on a treadmill (Davies et al. 2008). In their study, predictions of VO$_{2\max}$ from the perceptual ranges 9–17, 11–17, 7–17 and 9–15 were not significantly different to measured VO$_{2\max}$ values.

The aforementioned studies provided predictions of VO$_{2\max}$ by extrapolating to the maximal RPE on the Borg 6–20 scale. An interesting observation from several of these studies (Faulkner & Eston 2007; Faulkner et al. 2007a; Eston et al. 2006) was that participants typically reported an RPE of 18 or 19 at maximal volitional exhaustion. This finding has also been observed by others (Noakes 2004; Kay et al. 2001). Faulkner et al. (2007a) reported that extrapolation of submaximal VO$_2$ values to an RPE of 19 from the perceptual range 9–17 provided a more accurate prediction of VO$_{2\max}$ than when extrapolating to an RPE of 20.

Although repeat trials may be considered unsuitable for certain clinical populations, the proposed autonomy of self-regulating exercise intensity for some individuals (i.e. sedentary) may lead to greater exercise adherence (Faulkner et al. 2007a). The observation that VO$_{2\max}$ could be accurately predicted from a low-perceptually-regulated range (RPE 9–13; Faulkner et al. 2007a) has obvious importance for sedentary or clinical populations. In a later study on a separate group of 24 low-fit men and women, Faulkner et al. (2007b) predicted VO$_{2\max}$ with reasonable accuracy by extrapolating submaximal VO$_2$ values (prior to and including an RPE 13) from either a single graded exercise test (estimation) or perceptually-regulated exercise test to an RPE of 19. This is important because the affective state may become increasingly negative with increasing exercise intensity in such populations and potentially reduce the inclination to continue exercising (Parfitt et al. 1996; Hardy & Rejeski 1989). It has been reported that a lower perception of exertion during physical activity stimulates higher post-activity self-efficacy and that uncomfortable perceptions of exertion during initial efforts to increase physical activity are likely to discourage future activity (Robbins et al. 2004).

An alternative and highly novel approach to control exercise intensity is to allow the individual to self-regulate his/her exercise intensity to produce a positive affective response (Rose & Parfitt 2008). The Feeling Scale (FS) developed by Hardy and Rejeski (1989) has been recommended by Ekkekakis and Petruzzello (2002) to measure the valence (pleasure-displeasure, good-bad) component of affect. This is an 11-point bipolar scale anchored from very good (+5) through neutral (0) to very bad (−5). Individuals are asked to report how they feel at specific time points.

Rose and Parfitt (2008) assessed the efficacy of using the Feeling Scale as a means of regulating exercise intensity. In their study, 17 sedentary women (mean age, 44.8 ± 8.9 years) completed eight 30-minute laboratory-based treadmill exercise sessions. In four consecutive sessions, participants exercised at an intensity they perceived corresponded to an FS value of 1 (fairly good) and the other four sessions, at an intensity corresponding to an FS value of 3 (good). They observed that to achieve an affective state of good (FS 3), individuals exercised at a lower intensity (64% maximal heart rate, HR$_{max}$) compared to an affective state of fairly good (FS 1), which elicited an exercise intensity of 68% HR$_{max}$. These FS conditions equated to mean RPE values of 11.4 and 12.0, respectively. Across the four bouts of exercise at each condition, individuals consistently selected the same intensity to elicit a feeling state of good and fairly good. Across the 50 minutes in all of the exercise sessions, individuals also increased the intensity of exercise in order to maintain the required affective state. Whilst this is an isolated study, the principle is worthy of further investigation as it offers an alternative to using the RPE as the independent factor.
to control exercise intensity and considerable scope for exercise prescription for those who are most likely to drop out.

The RPE Scales with Time and Distance During Open and Closed Loop Tasks

Recently, a number of studies have observed a scalar linear relationship between the ratings of perceived exertion and the duration of exercise (Faulkner et al. 2008; Joseph et al. 2008; Eston et al. 2007; Noakes 2004). As noted by Noakes (2008), this relationship was originally described by Horstman et al. (1979), who to our knowledge were the first authors to observe that the rate of change in RPE during prolonged constant work could be used as a sensitive predictor of the point of self-imposed exhaustion. In their study, 26 healthy young men walked or ran at 80% VO\textsubscript{2max} to self-imposed exhaustion. In their study, 26 healthy young men walked or ran at 80% VO\textsubscript{2max} to self-imposed exhaustion. Despite significant increases in ventilation and ventilatory equivalent for oxygen and heart rate, oxygen uptake and the respiratory exchange ratio remained constant. Notably, the RPE was identical for both conditions, increasing in a linear function from approximately a value of 12.9 (at 25% of the total work time) to 18.9 at exhaustion. Importantly, they reported that the early pattern of change in RPE during prolonged work can be used as a sensitive predictor of the point of self-imposed exhaustion.

More recently, by reploting the mean data of ratings of perceived exertion against total exercise duration during a constant load cycling task at 70% VO\textsubscript{2max} from the study of Baldwin et al. (2003), Noakes (2004) showed a scalar linear relationship between the RPE and the duration of exercise in both carbohydrate-depleted and carbohydrate-replete conditions. Noakes (2004) hypothesised that if terminal RPE is similar in carbohydrate depleted and replete conditions, then perhaps the rate of increase in RPE may provide information indicating how close a participant is to the termination of exercise at exhaustion. Despite subjects exercising for 34% longer in the carbohydrate-replete state, Noakes (2004) observed that the RPE was indistinguishable between the two exercise conditions when it was plotted against a relative percentage of an exercise duration. Noakes (2004) therefore proposed that the brain increases the RPE as a proportion of the time that has been completed, or as a proportion of the time that remains.

These findings have been strongly associated with the theory of teleoanticipation, and more recently, the central governor model. These theories propose that the central nervous system continuously modifies the power output (pacing strategy) by modulating motor unit recruitment throughout the anticipated duration of exercise, to protect the body from catastrophic physiological and metabolic failure during exercise (St Clair Gibson et al. 2006; Noakes 2004, 2000; Hampson et al. 2001).

Intrigued by these observations, these postulations were tested by Eston et al. (2007). They confirmed previous observations by Horstman et al. (1979) and Noakes (2004) that a scalar linear relationship between the RPE and exercise duration exists. In an open-loop task to volitional exhaustion, they observed that although the rate of increase in the rating of perceived exertion was greater after a fatiguing bout of exercise, when the perceived exertion was plotted as a percentage of time taken for the exercise bout in either the fatigued or non-fatigued conditions, the rate of increase in perceived exertion was similar for both conditions (Figure 4).

These findings are also supported by the study of Joseph et al. (2008) which used “closed loop” tasks involving cycling time-trials of either 2.5 km, 5 km or 10 km. They reported the RPE to increase in proportion to the relative distance, regardless of the time-trial distance. Their study showed that the RPE increases in relation to relative distance, regardless of the distance performed, suggesting that the perception of effort has a scalar relationship with distance remaining during closed-loop exercise tasks. These data provide further evidence that the brain uses scalar rather than absolute time to set perceived exertion at any time point during an exercise bout, and that perceived exertion is set in an anticipatory manner from the start of the exercise bout.

Based on these findings, Faulkner et al. (2008) explored whether the scalar time properties of perceived exertion were evident during “closed loop” competitive distance running in the field. As research within the domain of teleoanticipation has focused on cycle ergometry in a laboratory environment (Joseph et al. 2008; Eston et al. 2007; Albertus et al. 2005; Kay et al. 2001), we were interested in determining whether the distance, course elevation (gradient), and variations in pacing strategy, coupled with the greater cardiopulmonary sensations of exertion experienced during running, altered the RPE-time relationship that had been previously demonstrated. The authors hypothesized that if the scalar teleoanticipatory theory of RPE was correct, the brain would take into account the environmental conditions (i.e. distance, course elevation) and manipulate the absolute RPE-duration relationship, but
maintain the relative scalar relationship between performance and RPE.

In our study, nine men and women completed a 7-mile (11.2 km) road race (7-MR) and the Great West Run half marathon (GWR: 13.1 miles, 21 km). Heart rate, split mile times and RPE were recorded throughout the races. The RPE was regressed against time and % time to complete the 7-MR and GWR and distance and % distance. As expected, although the rate of increase in RPE was greater in the 7-MR, there were no differences when expressed against % time or % distance. They concluded that as the course elevation, distance, pacing strategy and heart rate response varied between conditions, the perceptual response may be dissociated from such markers during distance running, thus confirming that the RPE scales with time and distance.

Research has shown that the ratings of perceived exertion may be influenced by the expected task duration (Baden et al. 2005). In their study, 16 well trained male and female runners completed three bouts of treadmill running at 75% of their peak treadmill running speed. In their first trial, participants were told that they would run for 20 minutes and subsequently ran for 20 minutes. In another trial, they were told to run for 10 minutes, but at the 10-minute mark, they were told to run for a further 10 minutes. In the final trial, they were not told how long they would run for, but all participants were stopped after 20 minutes. Results demonstrated
that RPE only significantly increased between 10 and 11 minutes for the trial in which participants were told to run for a further 10 minutes. Baden et al. (2005) suggested that perceived exertion is not purely a measure of physical exertion, as treadmill speed, heart rate and stride frequency remained constant throughout the entire duration of each of the exercise tests. In an earlier study, the RPE was shown to be inversely correlated with dissociative thoughts, confirming that runners pace themselves cognitively by manipulating their attentional focus (Baden et al. 2004).

Recent findings have also supported the suggestion that the RPE is set in a feedforward manner at the onset of exercise, altering power output to ensure that the RPE rises as a linear function of exercise duration, without risking physical harm (Albertus et al. 2005). Previous research has inferred that the RPE is dependent on physiological, psychological and subconscious processes that determine the duration of the exercise that remains, or anticipates the duration at the onset of exercise (Faulkner et al. 2008; Albertus et al. 2005; Noakes 2004). Evidence exists to suggest that the brain’s perception of effort across time is not influenced by incorrect feedback during long (Albertus et al. 2005) or short (Ansley et al. 2004) bouts of exercise due to a precise system of afferent feedback.

Effect of Carbohydrate and Caffeine Ingestion on the RPE

Research has also extensively examined the influence of carbohydrate and caffeine ingestion on the ratings of perceived exertion. Research has confirmed that carbohydrate supplementation can attenuate perceived exertion during prolonged bouts of cycling (Utter et al. 2007, 2002b; Backhouse et al. 2005). It has been suggested that this may be dependent upon the higher level of carbohydrate oxidation, higher plasma glucose and insulin levels, and lower plasma cortisol and growth hormone levels associated with carbohydrate supplementation (Utter et al. 2007, 1999). Backhouse et al. (2005) reported that the ratings of perceived exertion were significantly lower in a carbohydrate-supplemented compared to a water-placebo condition after completing 63% of the exercise task. As their study also observed that the participants had enhanced feelings of pleasure in the carbohydrate-supplemented condition, the authors postulated the importance of assessing not only “what”, but also “how” a person feels during exercise (Hardy & Rejeski, 1989). Conversely, some research has shown that carbohydrate supplementation has no attenuating effects on ratings of perceived exertion during resistance exercise (Utter et al. 2005) or during prolonged exercise with children (Timmons & Bar-Or, 2003).

The effect of caffeine ingestion on the ratings of perceived exertion during submaximal endurance exercise has also been examined. Typically, research has shown that caffeine attenuates perceived exertion during exercise (Demura et al. 2007; Hadjicharalambous et al. 2006; Doherty & Smith 2005). For example, lower ratings of perceived exertion have been reported when ingesting coffee during cycling of a long duration (Demura et al. 2007). This was evident despite no differences in physiological responses (heart rate, oxygen uptake, respiratory exchange ratio, plasma lactate concentration) between caffeine- and non-caffeine-supplemented conditions. Demura et al. (2007) suggested that caffeine ingestion before low-intensity endurance exercise may have a beneficial effect on psychological responses. It has been suggested that the reduced perception of effort following caffeine ingestion may be attributed to the direct stimulatory effect of caffeine on the central nervous system (Hadjicharalambous et al. 2006). However, in their study, the lower ratings of perceived exertion following caffeine ingestion did not correspond with an improvement in exercise performance. This contradicts the meta-analytical study of Doherty and Smith (2005) on the effects of caffeine ingestion on the ratings of perceived exertion, as they reported an 11.2% improvement in performance following caffeine supplementation.

Miscellaneous Studies on Perceived Exertion

In addition to the most prominent research on perceived exertion in the last 8–10 years, other research includes the assessment of exercise intensity on the relationship between the RPE and psychological factors (Hall et al. 2005), the association of the ratings of perceived exertion with the estimation of time remaining at a given intensity using an estimation of time limit (ETL) scale (Garcin et al. 2003; Garcin & Billat 2001), the RPE elicited during self-selected exercise (Ekkekakis & Lind 2006), and the influence of environmental temperature (Crewe et al. 2008; Tucker et al. 2006; Armada-da-Silva et al. 2004; Nybo & Nielsen 2001).

Although the ratings of perceived exertion continue to be predominantly assessed in healthy men, women and children, research has also examined the effort sense with various criterion groups. Studies have included patients with Brown-Séquard syndrome (Winchester et al.
2000), chronic obstructive pulmonary disease (Covey et al. 2001; Wadell et al. 2001), fibromyalgia syndrome (Nielens et al. 2000), multiple sclerosis (Thickbroom et al. 2006), chronic back pain (Wallbom et al. 2002), McArdles syndrome (Buckley et al. 2001), and visually impaired individuals (Buckley et al. 2000).

**Future Questions and Applications for the Ratings of Perceived Exertion**

Highly pertinent research questions have emerged from some of the perceived exertion themes that have been discussed. The EP curvilinear scale has the potential to explore a child’s perceptual framework during exercise. Future research could address the utility of the EP curvilinear rating of perceived exertion scales in both passive estimation and active production paradigms.

The novel application of the ratings of perceived exertion during an estimation-production procedure has many future implications and potential applications. As research has demonstrated accurate predictions of \( VO_{2\text{max}} \) from submaximal perceptually-regulated exercise tests with healthy men and women of high- and low-fitness, future research could be used to assess whether the ratings of perceived exertion can be used accurately and appropriately in a hospital-based or rehabilitation environment with unhealthy, sedentary men and women, and older members of the population. As such criterion groups exhibit a different response and tolerance to exercise (Parfitt et al. 1996), and if accurate estimates of maximal oxygen uptake are observed, it is more likely that the concept of using the RPE to predict \( VO_{2\text{max}} \) may become more widely applied by the health profession.

The utility of the RPE in the assessment of clinical populations in a hospital-based or rehabilitation environment may be highly pertinent, especially if utilizing a lower perceptual range to reduce the potential risks to health. Numerous practical and ethical concerns arise when adopting exhaustive exercise tests in non-athletic and patient populations. Not only are such procedures expensive, time-consuming and aversive to respondents, a high level of subject motivation is required to attain valid indices of maximal functional capacity. Future research should continue to assess and validate the effect of different durations of perceptually-regulated submaximal protocols on the prediction of \( VO_{2\text{max}} \) (Eston et al. 2006) and the efficacy of intermittent production procedures (e.g. Eston et al. 2008, 2005). Research has previously suggested that an intermittent testing procedure may be important if testing children at different exercise intensities and durations of physical exertion (Eston & Parfitt 2006; Lamb et al. 1997). The efficacy of using perceptually-regulated exercise tests to predict maximal oxygen uptake or maximal functional capacity in children has yet to be assessed and remains a question for future investigation.

Recent evidence has demonstrated a scalar linear relationship between the ratings of perceived exertion and the duration or distance of an exercise bout (Faulkner et al. 2008; Joseph et al. 2008; Eston et al. 2007; Noakes 2004). The findings observed in these studies have implications for the utility of the RPE to predict the time of exhaustion in both open- and closed-loop exercise tests. This may be evident regardless of the exercise intensity, environmental condition and physiological response to exercise. Further studies to examine the utility and application of these findings with both healthy and clinical populations would be useful. Although there is a growing body of evidence to suggest that it is the cognitive interpretation of the physiological responses to exercise which is perhaps the underlying mechanism for participation, compliance and exercise performance, further research is necessary to identify where the neuroanatomical and psychophysical bases for exercise performance exist (Marpora 2008). This line of research has yet to be undertaken in children.

Research has suggested that the anterior cingulated cortex, insular cortex, thalamus, dopamine, and endogenous opioids are important for the perception of effort and related decision-making (Marpora 2008; Salamone et al. 2007; Williamson et al. 2006, 1999; Craig 2002; Sgherza et al. 2002). Williamson et al. (1999) suggested that changes in right insular activity of the brain are related to exercise intensity and the ratings of perceived exertion. Recent neuroanatomical and neurophysiological results indicate that the insular cortex constitutes a basis for the subjective evaluation of one’s condition by processing sensations from all organs of the body (Craig 2002). During exercise, these interoceptive signals may be consciously monitored by the ratings of perceived exertion (Critchley 2004). How the scalar-internal timing mechanism operates, and where it is located in the brain, is still not well known. Research has recently suggested that a large number of widely distributed brain regions, including the brain stem and spinal cord, rather than a single specific brain region, may be involved in the processes underlying the internal timing mechanism (Miyake et al. 2004; Zakay & Block 2004). Although several theories have been proposed with regards to how the internal timing mechanism functions,
further research is required to clarify this. Marcora (2008) suggested that further studies on the origin, neural pathways, neurocognitive processes and sensory processing of corollary discharges are warranted. These are clearly areas for future investigation.

Conclusion

A critical review of the 21st century perceived exertion literature has provided a useful insight into concepts and themes that have dominated published findings. Research has continued to use the ratings of perceived exertion as an important construct to measure the psychophysical responses to exercise. Although prevalent themes have emerged since the turn of the century, it is our opinion that to further our knowledge within the realm of perceived exertion, it is unnecessary to continue validating various pictorial forms of the OMNI scale of perceived exertion. Research has previously shown, and has continued to demonstrate, that the Borg scales are effective tools for monitoring, prescribing and regulating exercise intensity in adults with normal cognitive ability. Novel research findings have been identified within the literature which have helped to progress our conceptual and mechanistic understanding of the ratings of perceived exertion. The prediction of maximal oxygen uptake from the ratings of perceived exertion and the scalar-linear RPE-time relationship are two such examples. Both research themes have practical implications and are highly recommended areas of future research in adults and children.

A further pertinent and recommended direction of research enquiry is to determine the neuroanatomical and psychophysical bases of exercise performance. In this regard, the use of brain imaging techniques during prescribed or self-regulated open and closed loop exercise tasks, with such tools as functional magnetic resonance imaging, has the potential to unveil highly significant advances in our knowledge of perceived exertion.

References


