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Use of Ratings of Perceived Exertion in Sports

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The rating of perceived exertion (RPE) is a recognized marker of intensity and of homeostatic disturbance during exercise. It is typically monitored during exercise tests to complement other measures of intensity. The purpose of this commentary is to highlight the remarkable value of RPE as a psychophysiological integrator in adults. It can be used in such diverse fashions as to predict exercise capacity, assess changes in training status, and explain changes in pace and pacing strategy. In addition to using RPE to self-regulate exercise, a novel application of the intensity:RPE relationship is to clamp RPE at various levels to produce self-paced bouts of exercise, which can be used to assess maximal functional capacity. Research also shows that the rate of increase in RPE during self-paced competitive events of varying distance, or constant-load tasks where the participant exercises until volitional exhaustion, is proportional to the duration that remains. These findings suggest that the brain regulates RPE and performance in an anticipatory manner based on awareness of metabolic reserves at the start of an event and certainty of the anticipated end point. Changes in pace may be explained by a continuous internal negotiation of momentary RPE compared with a preplanned "ideal rate of RPE progression" template, which takes into account the portion of distance covered and the anticipated end point. These observations have led to the development of new techniques to analyze the complex relationship of RPE and pacing. The use of techniques to assess frontal-cortex activity will lead to further advances in understanding.

***Keywords**:* effort, pacing, RPE, exercise intensity, perceptual regulation

The study of perceived exertion is an area of extensive research in exercise and sports science, as physical performance emanates from the complex interaction of perceptual, cognitive, and metabolic processes.[1] The rating of perceived exertion (RPE) involves the collective integration of afferent feedback from cardiorespiratory, metabolic, and thermal stimuli and feed-forward mechanisms to enable an individual to evaluate how hard or easy an exercise task feels at any point in time. The RPE is moderated by psychological factors (eg, cognition, memory, previous experience, understanding of the task) and situational factors (eg, knowledge of the end point, duration, temporal characteristics of the task). Whatever the age range, the use of the RPE in sport, exercise, and rehabilitation is founded on its strong relationships with exercise intensity (eg, work, speed, power) and physiological factors (eg, heart rate, ventilation, oxygen uptake, blood lactate). Under controlled conditions, the response of these factors to changes in temperature,[2] ambient partial pressure of oxygen,[3] and duration[4] tend also to be largely reflected in changes in the RPE.

The most common method of measuring the RPE in adults is the Borg 6–20 Category Scale[1] followed by the Borg Category-Ratio-10 scale (CR-10).[5] The development and correct use of these scales is described in detail by Borg.[1] As research questions and applications involving the perceptual response to exercise have developed, a number of additional scales for adults have been introduced in the last 15 years. These include the Session-RPE Scale[6] used in the calculation of training load; the Estimated Time Limit Scale[7] used in the estimation of the time remaining to volitional exhaustion; the adult OMNI Scales, which use numerical and mode-specific pictorial descriptors for resistance training,[8] cycling,[9] and walking/running[10]; and the novel Task Effort and Awareness Scale,[11] which is designed to separate and quantify the psychological and mental effort required to perform an exercise bout. As the antecedents of RPE include the memory of physical work experiences and the level of cognition and understanding, a number of simplified RPE scales for children have been developed. These scales use a limited number range based around 1 to 10 (eg, CERT,[12] BABE,[13] CALER[14]) or 0 to 10 (eg, OMNI Scale,[15] E-P Scale[16,17]) and wording that is more familiar to children. As the challenges and efficacy of assessing RPE in children have been described in detail elsewhere,[16,18,19] this commentary is limited to the use of RPE in adults.

The RPE has been applied in a variety of ways to assess and understand performance. Given the robust relationship between the RPE and measures of exercise intensity, particularly if this is known for an individual, the RPE is commonly used as a guide to the subjective assessment of exercise intensity. It may be used as a

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complementary measure to modulate or refine the prescribed exercise intensity of both cardiorespiratory and resistance exercise.[20] Although the most recent position statement of the ACSM holds that there is insufficient evidence to support using the RPE as a primary method of exercise training,[21] Parfitt et al[22] observed a 17% increase in aerobic capacity from a self-paced, 8-week treadmill training program (3 × 30 min/wk) clamped at RPE 13 in previously sedentary participants. In their study, the average exercise intensity produced during training at RPE 13 was 61% ± 7% of baseline maximal oxygen uptake (VO_{2max}) in week 1 and 64% ± 7% of the higher VO_{2max} in week 8. As subjects were blinded to speed, heart rate, and any other intensity feedback, this study provides strong evidence and proof of principle for the efficacy of RPE 13 (which was also perceived to be pleasant) to self-regulate training over a long period. The RPE is also a valid means of evaluating changes in training status and fitness using standardized submaximal-exercise test procedures, such as the Lamberts and Lambert Submaximal Cycling Test,[23] in which the RPE is one of 3 key variables that may indicate the development of fatigue (as subjects will have to work harder to elicit heart rates to 90% of maximal heart rate). The RPE has also become a popular method of assessing acute and chronic training load using the session RPE,[6,24] which is calculated by multiplying the relative perceived exertion of the session (scale of 0 to 10) by the duration of the exercise (in minutes) or the number of repetitions for resistance training.

Session RPE: Foster's 0–10 Scale and the CR-10 Scale

In a recent critique on the use of the session-RPE method,[25] I noted the absence of reference to the Borg CR-10 scale,[5] which is frequently and erroneously referred to in studies involving the use of session RPE to estimate training load. While it is recognized that Foster et al[6,24] used the CR-10 scale as the basis for creating a scale suitable for the session-RPE method (unfortunately reference is made to a study that describes a lesser known CR-20 scale[26]—an error that is frequently replicated in studies on session RPE), the modifications to the session-RPE scale have altered the numerical and psychometric properties of the CR-10 scale. Foster's 0–10 scale does not have the same number range as the CR-10 or the same semantic descriptors and fractionated scale as that originally described by Borg.[5] In addition, on the original Borg CR-10 scale, the number 10 is categorized as *very, very strong* [5] or *extremely strong,*[1] with the corresponding semantic descriptor of this level of exertion stated as *almost maximal,* not *maximal*—as in Foster's 0–10 scale. This is an important difference. The dot directly below the 10 on the CR-10 scale represents the final numerical magnitude of perceived exertion as people are permitted to "go beyond 10."[5(p380)] Theoretically, the absolute maximum RPE could be 12 or 13—that is, 20% or 30% higher than 10! Indeed, later versions of the CR-10 scale developed by Borg include further fractionations between 0 and 3 and an extension of the original range to "encourage responses of 1.5, 2.5 and above 10 up to maximal,"[1(p41)] with the dot described as the absolute maximum (highest possible).[1] As there are such critical differences in the numerical and psychometric properties of the CR-10 and Foster's 0–10 scales, to avoid confusion I suggest that reference to the use of a CR-10 scale be avoided when using Foster's scale in future studies. The method of assessing RPE used to calculate the session RPE could simply be referred to as the Foster or session-RPE scale.[6] While we recognize the limitations of the session-RPE method,[25,27] it is clear from the literature that Foster's scale has proven practical value, is simple to apply, and has become a popular and valid means of estimating training load across a wide range of activities.

The Value of RPE as a Psychophysiological Integrator

The RPE has remarkable value as a psychophysiological integrator that can be used in diverse fashions to predict exercise capacity and to explain changes in pace and pacing strategy.

Prediction of Maximal Exercise Capacity and Critical Power Using the RPE

The ability to estimate maximal functional capacity with acceptable accuracy from submaximal exercise testing is advantageous for monitoring training status. It has been known for some time that the RPE elicited from submaximal increments in a graded exercise test (GXT) can be used to provide estimations of VO_{2max} that are as good as, or better than, heart rate. Morgan and Borg[28] observed that the linear relationship of RPE and work rate during a GXT in physically active and sedentary men permits extrapolation to a theoretical end point, enabling the prediction of maximal work capacity with better accuracy than heart rate. Studies have confirmed the efficacy of submaximal RPE to estimate VO_{2max} or maximal work rate from standard GXT in healthy active and sedentary groups,[29–31] club runners,[31] and able-bodied and paraplegic athletes[32]; from ramped protocols in sedentary and athletic subjects[32,33]; and from randomized workloads in competitive cyclists.[34] The RPE from the 20-m shuttle-run test may also be used to predict VO_{2max}.[35] Recent evidence also suggests that the RPE can be used to estimate a 1-repetition maximum in adults[36] and children,[37] predict maximal performance of intermittent vertical-jump exercise, and describe the physiological demands of such exercise.[38]

A further innovative application of the RPE is in the calculation of critical power, [39] which has been used extensively to assess athletes' endurance capacity. However, the necessity for subjects to perform a number of exhaustive efforts on separate days has precluded its routine use. Nakamura et al[39] validated a "perceived exertion threshold" procedure by which the rate of increase in the RPE (as assessed by RPEs of 14–17) across 4 exhaustive efforts was regressed against power output. This method of estimating critical power was shown to be remarkably accurate and reliable and to avoid causing exhaustion.

Prediction of Maximal Exercise Capacity From Perceptually Regulated Exercise Testing

On the basis that RPE alone may be used to regulate exercise intensity,[14,22,40–45] perceptually regulated exercise testing (PRET) has been proposed as an alternative method of estimating maximal exercise capacity and training status. This method has the advantage of allowing subjects the autonomy to set the intensity of exercise to a given RPE through changes in pace, work rate, or gradient. The procedure was first applied successfully in cardiac patients[46] and has since been confirmed across a broad range of age and fitness levels in adults for cycling,[47–51] treadmill,[31,52] and wheelchair exercise in able-bodied and paraplegic athletes.[53] The standard submaximal PRET procedure (with the exception of Morris et al,[51] who used a randomized PRET procedure) involves a series of short incremental stages (2, 3, or 4 min) that are clamped to RPEs of 9, 11, 13, 15 and sometimes 17. Extrapolation of the individual RPE:intensity relationship to a maximal RPE (19 or 20) enables VO_{2max} or maximal work rate to be estimated with reasonable accuracy.

PRET, VO_{2max}, and Theoretical Maximal Perceived Exertion: The Elusive RPE-20, or "Dot" Below the 10!

The theoretical maximal RPE (ie, RPE 20) is infrequently reported at volitional exhaustion during standard GXT or maximal incremental exercise tests (MIEs),[20,31,32,49,50,52–56] ramp exercise tests in able-bodied and paraplegic athletes,[32] simulated time trials,[57,58] and constant-load tests to maximal volitional exhaustion.[54,59] The subjective limit of fatigue normally occurs around RPE 19 (*extremely hard*) on the Borg 6–20 scale. It is therefore not that surprising that several studies have reported more accurate predictions of VO_{2max} when RPE 19 is used as the extrapolation end point in active and sedentary subjects,[31,50,52] recreational club runners,[31] and competitive cyclists,[34] as this tends to correspond more closely with the maximal RPE that is reported during standard exercise testing for VO_{2max}. In this regard, it is worth noting Borg's comparison of the RPE values from the 6–20 scale with those from the CR-10 scale.[1] The transformation table shows that RPE 19 equates to 10 and RPE 20 equates to 12 on the CR-10 scale.

In view of all this, it is interesting to note the findings from a novel study by Mauger and Sculthorpe,[60] who compared the VO_{2max} from an MIE test and a maximal PRET in untrained young men and women. The rationale for their study was partially based on current debate over the limitations of the typical VO_{2max} test in its current open-loop form, which, it is argued, negates the role of the brain.[61] In a standard MIE the subject is a passive recipient of increases in exercise intensity and is unaware of the end point, a factor that has been shown to be critically important for the subjective regulation of pace and power output.[62,63] Using a similar PRET procedure as in previous studies[46–53] with RPE clamped at 11, 13, 15, and 17, but with the important exception that the final RPE-regulated stage was clamped at RPE 20, the VO_{2max} elicited during the maximal PRET procedure was approximately 8% higher than that observed in the MIE. As observed in previous studies, the maximal RPE during the MIE was 18.9 ± 1.2, with a range of 17 to 20 (personal communication). Cycling at RPE 20 in the self-paced PRET procedure, that is, making an all-out sprint to the end with 2 minutes to go, resulted in the highest immediate increase in power output (mean 70 v 30 W) with a commensurately greater increase in oxygen uptake compared with the previous RPE stages. It is not surprising that with subjective intensity clamped at RPE 20 to elicit the absolute maximal possible effort, the untrained participants were unable to maintain power output for much longer than a few seconds. Immediately after the initial surge, power output decreased by ~40 W in the remaining 90 s of the test, although the mean power output in the final stage was similar to that observed in the MIE.

The observation that a higher VO_{2max} may be elicited from a self-paced test, which allows autonomy of control and facilitates anticipatory regulation of work rate up to a known end point (RPE 20), is indeed very interesting and provides further support for the role of the brain in limiting maximal exercise performance.[64] However, as those authors acknowledged, a critical limitation in their study was the substantially longer duration of the GXT (13 ± 3 v 10 min), which ranged from 8 to 18 min, with 9 of the 16 subjects taking longer than 12 minutes to achieve VO_{2max} (personal communication). To elucidate potential mechanisms that might explain the difference in VO_{2max} obtained by standard MIE and PRET (if the difference is real and not an artifact of the duration of the test), future studies must control the duration of the test, as VO_{2max} test protocols >12 minutes are likely to induce a lower VO_{2max}.[65,66] I suggest this be done by comparing a traditional MIE with one of identical duration but that includes a self-paced effort at RPE 20 in the final stage.

RPE and Its Relationship With Time or Distance Remaining and Estimated Time Limit to Exhaustion

During prolonged submaximal exercise to exhaustion, the RPE rises or drifts as a linear function of the percentage of total exercise duration. This was first observed by Horstman et al[67] in a study that required subjects to walk or run at 80% of VO_{2max}. They reported that the early pattern of change in RPE during prolonged work could be used as a sensitive predictor of the point of self-imposed exhaustion.

Interest in this phenomenon was revitalized by Noakes,[68] who proposed that perceived exertion is set in an anticipatory manner from the start of the exercise bout, implying that the brain increases the RPE as a proportion of the time that has been completed or the percentage of time that remains. Noakes' note stimulated a flurry of studies to explore the phenomenon,[2,54,57,62,69–71] the first of which[54] showed that prior fatiguing activity shifted the relationship between exercise time and RPE growth during an open-loop task at 70% VO_{2max} to volitional exhaustion. However, when expressed as a proportion of the total exercise time for the prefatigued and nonfatigued conditions, the growth of RPE compared with the percent time completed was similar and constant, suggesting that the growth of RPE is scaled to task duration. The results of Eston et al[54] confirmed initial observations of Horstman et al[67] and Noakes[68] that showed that when the RPE is expressed against the proportion (%) of the time or distance completed, regardless of the length of an effort, it rises similarly relative to the percentage of distance or duration completed or yet to be completed.[57] This holds true in studies where the duration of open-loop, fixed-intensity exercise was manipulated by varying environmental conditions[2] or by exercise-induced muscle damage[72] and during closed-loop tasks (the duration or distance to the end point is known) despite the effects of hyperoxia,[73] hypoxia,[3] temperature,[74] and varying competitive distances.[57,62,69]

The findings suggest that the brain regulates RPE and physical performance in an anticipatory manner based on the awareness of metabolic reserves at the start of an exercise bout and that it is constantly in some sort of "internal negotiation"[57] whereby the exerciser compares the current exercise bout with that of previous experiences and current environmental conditions. Awareness that the rate at which the RPE increases as a key variable that regulates performance during prolonged endurance exercise has led to the idea of a model in which the RPE is compared with a "template" of an ideal rate of RPE progression, which is planned before the event and that is compared with the "conscious RPE."[75] The scalar property of the RPE also suggests that the anticipated end point is taken into consideration at the start of an exercise bout.[57] Indeed, certainty about the exact duration and end point have been shown to affect both RPE strategy and performance, as the rate of increase in perceived exertion is not always constant in all conditions but changes in relation to the degree of certainty about the end point of exercise, as well as exercise duration.[62] The disruption in the rate of RPE increase has also been demonstrated when uncertainty about the anticipated end point is invoked by deliberate deception during fixed-intensity cycling[76] and treadmill exercise.[77]

The practical implications of this knowledge should mean that it is theoretically possible to use the rate of increase in the RPE to estimate the exercise duration or time remaining to exhaustion at a given work rate or pace, although as far as I am aware, this remains to be proven in practice. In addition, it seems that athletes continually compare their momentary or conscious RPE with an expected RPE (the template RPE) through a process of internal negotiation at a particular portion of a race and adjust pace to match the anticipated and experienced values for RPE.[57,78]

The Hazard Score and the Task Effort and Awareness Scale: New Methods to Explain the Role of the RPE in Exercise Regulation

Two recent and highly novel studies by de Koning et al[63] and Swart et al[11] shed further light on the process of internal negotiation and the decision to change pace during race or time-trial situations. By retrospectively integrating the RPE and velocity data from 9 separate competitive simulation experiments with runners and cyclists, de Koning et al[63] showed that the likelihood of changing velocity was related to a simple index of the momentary RPE and the percentage of the event remaining, which reflects the fundamental strategy by which athletes regulate their effort during competition. The product of the momentary RPE and the proportion of distance remaining (the hazard score) provides an informative tool to describe an athlete's tendency to change to faster or slower velocities at given proportions of the relative distance to the end point. In a further study to understand the role of RPE in competitive situations, Swart et al[11] developed a novel 15-point (–4 to +10) perceptual scale—the Task Effort and Awareness scale—to differentiate the possible independent effects of the physical and psychic sensations generated during exercise. They showed distinct rates of progression for the sense of effort and the physical sensation of exertion (RPE) during mixed-intensity exercise, providing evidence that the sense of effort and the physical sensations of exercise are distinct but related perceptual cues that play a critical role in the regulation of exercise intensity. Their data support the interpretation that exercise is regulated centrally in the brain and show that if the exercise workload exceeds that required to maintain a predetermined RPE template, an increased conscious sense of effort is generated. The Task Effort and Awareness scale and hazard score are methods that provide innovative complementary techniques to further understanding of the central role of the RPE in the regulation of pacing strategy during competition.

Direct Measurement of Anticipated Time to Volitional Exhaustion

It is important to recognize that the concept of estimation of time remaining to exhaustion based on the momentary RPE was independently proposed by Garcin et al[7] over a decade ago. 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, they introduced the 1- to 20-point scale based on the subjective estimation of exhaustion time (the Estimated Time Limit [ETL]), in which, for example, the numbers 17, 13, 9, and 4 relate to an anticipated end time to exhaustion of 4, 15, and 60 minutes and 2 hours, respectively. The ETL scale provides further information on the psychological load (intensity and duration) of exercise and allows for a direct subjective estimation of time that can be maintained at any intensity and at any given instant.[79] Evidence from a recent study on male athletes shows that the ETL scale may also be used to regulate exercise intensity.[80] Use of the ETL scale, in conjunction with the RPE, provides a further unique and practical method of understanding the relationship between perceived exertion, exercise intensity, and the duration that remains until physical exhaustion. It may also be used to assess performance and training status and as a means of individualizing exercise training.

Conclusion

The RPE is valid for monitoring, prescribing, and regulating exercise intensity and assessing training load. It has been used to explain changes in pace and pacing strategy, as the rate of RPE progression during competitive situations is related to duration and certainty of the end point. It may also be used to predict exercise capacity during a standard GXT and when using self-paced procedures clamped by RPE. Limited evidence suggests that maximal, self-paced exercise testing clamped at RPE 20 may provide a more accurate measurement of VO_{2max}, although this remains to be shown convincingly. To really understand some of the processes and to fully examine the mechanisms of how the RPE is formed during self-regulated and prescribed loads of high- and low-intensity exercise in open- and closed-loop situations, it will be important to examine the role of the brain more directly in future studies. A combination of techniques to assess neurological activity during exercise, such as electroencephalography, multichannel near-infrared spectroscopy, and, with sufficient control for movement artifact, functional magnetic resonance imaging, will lead to significant advances in our understanding of the anticipatory and regulatory nature of the RPE. Near-infrared spectroscopy can be used to assess cerebral oxygenation during exercise on most laboratory ergometers, making it a realistic option currently available for the assessment of human cortical activity during exercise.[81,82]

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