Role of Ratings of Perceived Exertion during Self-Paced Exercise: What are We Actually Measuring?

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Abstract  Ratings of perceived exertion (RPE) and effort are considered extremely important in the regulation of intensity during self-paced physical activity. While effort and exertion are slightly different constructs, these terms are often used interchangeably within the literature. The development of perceptions of both effort and exertion is a complicated process involving numerous neural processes occurring in various regions within the brain. It is widely accepted that perceptions of effort are highly dependent on efferent copies of central drive which are sent from motor to sensory regions of the brain. Additionally, it has been suggested that perceptions of effort and exertion are integrated based on the balance between corollary discharge and actual afferent feedback; however, the involvement of peripheral afferent sensory feedback in the development of such perceptions has been debated. As such, this review examines the possible difference between effort and exertion, and the implications of such differences in understanding the role of such perceptions in the regulation of pace during exercise.

Key Points

Rating of perceived exertion scales have been used within the literature to assess both effort and exertion, although evidence exists to suggest that these are slightly different constructs.

It is plausible that the neural processes involved in the development of perceptions of effort and exertion differ.

Examination of the difference between effort and exertion may aid in improving our understanding of the role these perceptions have in the regulation of pace during exercise.

1 Introduction

The distribution of speed or energy expenditure throughout an exercise task is known as pacing and is extremely important to overall performance. As a result, research aimed at understanding the underpinning mechanisms influencing the selection of pace during exercise has dramatically increased within recent years. From this research, the regulation of intensity during exercise appears largely regulated by complex relationships between the brain and other physiological systems, with several models proposed...
to explain this phenomena, including the central governor model [1], teloanticipatory theory [2], pacing awareness model [3], psychobiological model [4, 5], the flush model [6], perceptions-based model [7] and complex systems model [8, 9]. Many of these models indicate that afferent sensory feedback from various physiological systems is received by the thalamus and regulated within the brain [1, 2, 5, 9]. This information, in addition to several other factors such as knowledge of the task duration/distance remaining, memory of past similar experiences, motivation and mood [5, 10], is believed to be important in the regulation of pace.

Important aspects within many of the abovementioned models include the participants’ perception of exertion, perception of effort and the task demands [7, 11]. Indeed, it has been suggested that exercise intensity is regulated based on one’s perceived exertion in order to ensure that ‘catastrophic’ or ‘critical’ disturbances to homeostasis do not occur [1, 2]. This is supported by the relatively stable increase in perceived exertion that is typically observed during high-intensity, self-paced exercise (i.e. a time trial) [12, 13]. Indeed, it has been proposed that the product of the momentary perceived exertion and the fraction of distance remaining (referred to as a hazard score) may provide an indication of changes in intensity during self-paced exercise [11]. Importantly, it has also been suggested that one’s perception of effort is centrally derived and largely unaffected by peripheral afferent sensory feedback; however, the role of afferent feedback in the regulation of intensity during self-paced exercise has been debated [14–16]. Such uncertainty may be associated with slight but important differences between the terms effort and exertion and the measurement tools used to assess an individual’s perceptions during exercise. As such, the purpose of this review was to (i) highlight possible issues associated with the measurement of perceptions of effort and exertion; (ii) outline the role of the brain in the development of such perceptions; and (iii) provide suggestions for research to better understand the role of such perceptions on the regulation of pace during exercise.

2 Monitoring Perceptions of Effort and Exertion

To date, a number of subjective tools have been developed to determine a participants’ localized (i.e. chest, arms or legs) or whole-body ratings of perceived exertion (RPE) during exercise [17, 18]. The most common of these include Borg’s 6–20 rating of perceived exertion scale, and Borg’s CR-10 and CR-100 scales. Modifications of these scales have also been developed to examine symptomatic breathlessness (Modified Borg Dyspnoea Scale) or pain during exercise [17]. These scales are very easy to use and as a result have been extremely valuable in understanding the psychophysiological stress experienced by humans during physical activity [18–20]. Regardless, the factors that influence one’s RPE during exercise are extremely complicated as RPE is believed to be influenced by numerous factors, including effort, strain, pain, discomfort and/or fatigue [2]. A higher RPE is typically associated with increased physiological stress and fatigue. Indeed, numerous studies have shown that significant physiological perturbations, such as an increase in heart rate, ventilation, oxygen consumption, and metabolic acidosis (decrease pH), result in greater RPE [17, 21, 22]. Consequently, the association between changes in RPE and physiological status (i.e. oxygen consumption, heart rate) have been used as evidence of the strong concurrent validity of the RPE scale [17, 23, 24].

Clearly, RPE is an important variable in understanding the psychophysiological stress experienced during a variety of physical tasks; however, it is possible that administration of RPE scales differs slightly among laboratories. Notably, throughout the literature RPE has been referred to as perceived exertion and a perception or sense of effort [25]. Some studies have also alternated between the terms perceived exertion and perceived exhaustion [26]. However, it has been proposed that the exertion, which may be associated with physical and physiological stress induced as a result of exercise, is distinctly different from perceptions of effort [27, 28]. Indeed, exertion has been defined as the “degree of heaviness and strain experienced in physical work” [17], whereas effort may be defined as ‘the amount of mental or physical energy being given to a task’. Confusion between these terms is even evident in the original derivative of the RPE scale where in Borg’s manuscript entitled Psychophysical Bases of Perceived Exertion it is stated that “there is a great demand for perceptual effort in order to better understand man at work” [18]. Later in the manuscript, Borg states that “the individual’s perception of exertion during physical work is interesting” and that in his opinion “perceived exertion is the best indicator of the degree of physical strain” [18]. Thirty-plus years on, this confusion still exists, with the American College of Sports Medicine current comment on perceived exertion stating that RPE “is a psychophysiological scale, meaning it calls on the mind and body to rate one’s perception of effort” [29]. Recently, it has also been suggested that ‘perceived exertion’ is a conscious manifestation of the feelings of effort produced by exercise [7, 30, 31].

Directions given to participants, or the precision of the questions asked when implementing an RPE scale, could influence the response given and as a result may have considerable implications in understanding the psychophysiological stress during a task and the role of RPE in the regulation of self-paced exercise. Indeed, it is important
to consider the particular research question which RPE is being used to assess when administering RPE scales. Within sports science research RPE is often taken as a secondary measure in order to vaguely describe one’s sensations during exercise. As such, it is plausible that the primary research measure, and ultimately the study design, may influence one’s interpretation of the RPE scale and the response given. While clear instructions are provided as to how to deliver Borg’s RPE scales, these instructions may not be ideal since they mention both exertion and effort [17]. Furthermore, while the anchor points provided with the scale (i.e. light, somewhat hard, maximal exertion) may assist participants in understanding the purpose of the scale, it is possible that the terminology used when describing this or similar scales may influence the interpretation of the scale. Indeed, a recent study by Swart et al. [27] has found that participants are able to distinguish between physical perceived exertion (using a modified Borg Scale) and task effort and awareness. Furthermore, it was found in this study that there was dissociation between these two variables when exercising at low or maximal (i.e. all-out) intensities (Fig. 1). In agreement with these findings, we have also observed differences in the rate of increase in perceptions of pain (% change = 6.9 ± 4.1), exertion (16.4 ± 7.6) and effort (2.0 ± 2.2) during three repeated maximal, high-intensity 4-min efforts (unpublished data). Furthermore, we have found that during single-leg cycling, perceived exertion may be lower but perceptions of effort and pain are similar to double-leg cycling [32]. Possible differences between effort and exertion may also explain why many participants are unable to reach maximal exertion during various exercise tasks. For instance, while the Borg scale’s upper anchor is 20 (i.e. maximal exertion), the published criterion for the determination of maximal aerobic capacity has been a rating equal to or greater than 17–18 (i.e. very hard) [33]. Clearly therefore, a large proportion of participants who complete a graded exertion test fail to reach maximal exertion, despite participants being asked to exercise to volitional exhaustion. However, it is plausible that if exercise is limited by muscle strength, anaerobic energy contribution or other similar factors, the participants’ effort is maximal but exertion slightly lower. However, to date few studies have used a number of these perceptual scales concurrently during exercise [27, 32] and thus the difference, importance and relationship between these variables is not entirely clear. Furthermore, the independent influence of each of these perceptions on pacing and performance during exercise is not known.

It is plausible that alterations in the contribution of central and peripheral fatigue that occur during exercise can influence the association between effort and exertion. De Morree and Marcora [25] observed significantly higher RPE values with a corresponding lower power output at the beginning (minutes 1 and 3) of a 15-min cycling time trial after a pre-exercising eccentric fatiguing protocol (100 drop-jumps). The authors state that maintaining the same pace with fatigued locomotor muscles would have resulted in higher RPE and premature exhaustion [25]; hence, participants decide to reduce their pace so that the RPE does not reach its maximum before the end of the trial. Furthermore, when the capacity to produce force is reduced, more effort than normal is required for the same task [15]. However, in this study participants were given standard instructions on how to rate their perception of effort on Borg’s 6–20 RPE scale. As previously mentioned, effort may be defined as ‘the amount of mental or physical energy being given to a task’. Hence, it is plausible that the higher RPE values observed were because participants were, at least in part, rating the amount of mental and physical energy they were investing in an attempt to achieve a similar power output as in the non-fatigued condition. In contrast, a recently published study analysing the effects of accumulated short-term fatigue on performance and pacing during a 40-km cycling time trial showed significantly lower power output during a time trial in a fatigued state, yet no difference in corresponding RPE values, when introducing RPE as a “degree of heaviness and strain experienced in physical work” (perceived exertion) [34]. Together, these findings highlight the possibility that either the type of fatigue induced (i.e. acute vs. accumulated; local vs. multifaceted), or the terminology used when describing the Borg RPE scale, may have influenced the response given.

Language and/or translation of terms may be another important issue responsible for some confusion over the use of the terms effort and exertion. According to the Oxford English Dictionary [35], exertion and effort are synonyms. Furthermore, when searching translations for both words, dictionaries of various languages (e.g. German, Spanish, Italian, Portuguese, Dutch and Japanese) often provide the same word for both ‘effort’ and ‘exertion’. Taking this into account, it is plausible that authors may use both terms interchangeably. In a broader sense, it may be speculated that speakers with English as a second language use the RPE scale differently, depending on their ‘interpretation’ of the translated term. For example, the German translation for effort and exertion is the same term (‘Anstrengung’). Furthermore, depending on the context of the term, ‘Anstrengung’ can be used with regard to the degree of heaviness experienced or the degree of energy given to a task. When reviewing manuscripts published by German researchers, it appears that the explanation of Borg’s RPE scale may be defined as an “expression of the subjective feeling of the heaviness of a given work load or intensity” [36]. Hence, several factors seem to influence
the introduction and delivery of the RPE scale, especially when translated into other languages, including (i) the translation of the original definition; (ii) the ‘interpretation’ of the translated term; and (iii) the instructors’ and participants’ understanding of these terms.

3 Perceptions and the Brain

3.1 Neural Regulation of Perceptions

To fully understand the complex relationship between exertion, effort and pacing, an appreciation of how such perceptions are developed and regulated within the brain is necessary. Indeed, the development of perceptions, interpretation of language and sensations associated with effort and exertion during exercise involve multiple regions within the brain. The brain is an organ of communication. Neurons within the brain connect in networks that communicate with each other to provide multiple functions. This network organization is particularly evident with regard to cognition, which involves the participation of diverse brain areas, including parts of the limbic system such as the hippocampus, amygdala, frontal cortex, thalamus, etc. Multisensory integration in the brain deals with the processing of information from the different sensory modalities, such as sight, sound, touch, smell, self-motion and taste [37]. Multisensory integration also deals with interaction of various sensory modalities and how each sensory modality influences other processing [38]. Furthermore, during intense exercise this is made even more complicated by considerable disturbances to physiological homeostasis, creating the need for considerable communication and computing within the brain and with peripheral physiological systems. As such, perceptions may reflect how the brain integrates and categorizes the input signals resulting from various different stimuli.

Perceptions of effort and exertion are believed to be closely related to activity within various areas of the motor cortex, including the premotor and primary motor areas [39]. Indeed, the well-accepted corollary discharge theory postulates that an efference copy of the central motor command is sent directly from motor to sensory areas of the brain in order to assist in the generation of perceptions associated with motor output (Fig. 2) [40–43]. As such, the close relationship between RPE and muscle activity (i.e. electromyography) during exercise is thought to be largely influenced by a central feed-forward neurophysiological mechanism whereby as motor unit recruitment and firing
frequency increase, the number of efferent copies received by sensory regions within the brain also increases [39, 44, 45]. This theory is supported by the relationship between perceptions of effort or exertion and the increase in central drive required to exercise at higher intensities and/or during periods of muscle weakening resulting from peripheral fatigue [46] or partial paralysis [47, 48]. Indeed, we have recently shown that elevated peripheral fatigue and a concomitant increase in central drive is associated with an increase in RPE during constant-load, high-intensity cycling [46]. Furthermore, De Morree et al. [39] have also recently observed an association between perceived effort and the amplitude of the movement-related cortical potential, which reflects activity within the premotor and motor areas of the brain [49]. Based on this, the authors suggested that perception of effort might arise from the primary motor cortex [39]; however, the authors also highlighted the possibility that perceived effort may be associated with activity in neural centres upstream of the primary motor cortex, and possibly even the motor cortex [39, 50]. Due to their involvement in homeostatic control, awareness [51], emotion, error detection, motivation and pain [52], higher brain centres such as the insular cortex and cingulate cortex are believed to be extremely important in perceptions that are associated with physical activity [30, 53, 54]. Supporting this, Fontes et al. [30] observed an association between increased neuronal activity in the posterior cingulate gyrus and precuneus and rating of perceived exertion during cycling. Furthermore, an increased activation of the right anterior insular cortex has been documented with increased perceived exertion during dynamic exercise [55, 56]. Interestingly, it has also been found that increases in activation of regions within the insular cortex and anterior cingulate cortex may be the direct result of central command per se, and independent of muscle metaboreflex activation or changes in blood pressure [56].

In addition to the efference copy, afferent information is believed to be extremely important in the development of perceptions of effort and exertion during exercise (Fig. 2) [31, 47]. Indeed, it is believed that effort is associated with not only corollary commands received by the sensory cortex but also expected reafference arising from the motor drive (Fig. 2) [40, 47]. Indeed, Luu et al. [47] showed that by reducing muscle force using a neuromuscular blockade, sensations of heaviness were reduced, presumably due to reduced peripheral feedback associated with paralysis of muscle spindle intrafusal fibres, since it was assumed that motor command must have been elevated. Aligned with this hypothesis, it has recently been proposed that exercise-induced pain is an important contributing factor in the regulation of work intensity and is thus important in pacing during exercise [57]. It has been shown that an opioid analgesic to selectively block the activity in ascending sensory pathways results in elevated RPE during a 5-km cycling time trial [58]. However, within this study, impaired muscle afferent feedback was also associated with altered central motor drive [58], and thus it remains unclear whether an alteration in corollary command, rather than changes in afferent feedback, was the dominant mechanism responsible for altered RPE. Regardless, based on the current literature it appears reasonable to suggest that such regions of the brain are responsible for the integration of physiological afferent signals from the periphery to promote emotional and conscious control of perceptual stress during exercise [30]. Under such a hypothesis, perceptions of both effort and exertion are likely to be dictated by not only the discrepancy or balance between predicted and actual sensory feedback but also other complex psychological factors such as memory/prior experience of similar exercise [2], motivation [8], positive and negative affect [10] and awareness [2].

However, it should be noted that the aforementioned blockade studies have examined sensations of heaviness

![Fig. 2](image-url)
transmitters in the integration of signals within the brain is crosstalk during exercise [47]. All are linked with limbic processing of signals and will influence the neural functions outlined above (Sect. 3.1), and it is clear that these neurotransmitter systems will work ‘in concert’ to establish the integration of all information and information processing in the brain.Monoaminergic neurons modulate a wide range of functions in the central nervous system. Noradrenergic neurons are involved in cardiovascular function, sleep and analgesic responses, while dopaminergic neurons are linked with motor function and motivation, and serotonergic activity is associated with pain, fatigue, appetite and sleep [60]. Other transmitters, such as adenosine, glutamate, gamma-butyric acid and others, are also influenced by disturbances of homeostasis. All are linked with limbic processing of signals and will crosstalk during exercise [61]. The influence of neurotransmitters in the integration of signals within the brain is likely to be especially important during intensive and/or long-duration exercise. Indeed, it has been found that even acute exercise increases the release of neurotransmitters in several brain areas [61]. Our recent research showed that not only climatic stress but also pharmacological manipulation of the neurotransmitters has the ability to cause changes in endurance performance [62]. Furthermore, it has been found that such pharmacological manipulation alters pacing, specifically in the early phases of an exercise task [63]. For instance, manipulations of serotonin, especially noradrenaline, result in a decrease in power output during the early stages of a time trial. However, dopamine reuptake inhibition has the opposite effect and subjects are able to maintain a higher power output compared with placebo. When neurotransmission is manipulated through a selective serotonin reuptake inhibitor, subjects are often unable to perform an end sprint, indicating an absence of a reserve capacity or motivation to increase power output [62].

Although pacing and/or overall performance may be altered when neurotransmitters are manipulated, typically no differences in perceived exertion or thermal stress are observed when compared with placebo trials [64–67]. It has been proposed that participants continuously modify their pace in order to match the momentary perceived exertion with the expected level of exertion at a given point during an exercise task [11]. As such, drugs acting to enhance brain dopamine would change the initial anticipatory setting of work rate by elevating arousal and motivational levels. Under such circumstances, perceived exertion may be reduced, resulting in a mismatch between the actual and template perceived exertion. Consequently, this would lead to an increased work rate and heat production, until the conscious perceived exertion returns to anticipated levels. In contrast to dopamine, an increase in brain noradrenaline concentration has detrimental effects on power output and thus exercise performance. Despite the lower power output when manipulating the noradrenergic system, perceived exertion between conditions has been shown to be similar [62].

Taken together, it appears that performance-enhancing or -retarding effects of central nervous system drugs on endurance performance are reflected by changes in the distribution of pace during exercise. In the presence of larger climatic stress, subjects seem to adapt their strategy specifically in the earlier phases of exercise. Such alterations in exercise intensity may be in order to ensure exercise is performed at a given level of perceived exertion (i.e. the RPE template). Indeed, perceived exertion is typically not influenced by the drug treatments outlined above, indicating that subjects maintain the same level of exertion, regardless of the power output produced or the core temperature achieved. Nonetheless, to date the majority of...
studies that have examined the association between pacing and neurochemistry have examined perceptions of exertion and thermal sensation, rather than perceived effort. Similar manipulation trials may be valuable in better understanding the relationship between pacing or exercise performance and various perceptions, including both effort and exertion.

4 Future Research that May Aid in Better Understanding the Role of Ratings of Perceived Exertion in Pacing

Many of the issues outlined in this review centre on the inconsistent use of the terms exertion and effort. We have highlighted not only possible neurological differences in the way individuals perceive exertion and effort but also issues with the explanation of the perceived exertion scale. Specifically, the instruction provided, or questions asked, when implementing the scale are likely to influence the measured outcomes. To address this issue, studies designed to independently assess both effort and exertion are needed. Such work should build on that of Swart et al. [27] and examine the influence of an individual’s ability to distinctively differentiate exertion and effort. Given that there is evidence for dissociation between perceptions of effort and exertion during exercise of varying intensity [27] or total muscle recruitment [32], it may be interesting to conduct such research during various modes of exercise. Indeed, manipulation of factors such as the level of eccentric loading, exercise intensity, task familiarity or external mental requirements may alter the association between effort and exertion during physical activity. Although extremely complicated, these studies should also focus on the mechanisms and neural process responsible for changes in perceived exertion and effort during exercise. Examination of regional brain activity (i.e. functional magnetic resonance imaging, electroencephalography or cerebral blood flow) or alterations in neural function (i.e. manipulation of neurotransmitters or direct current stimulation) may assist in better understanding the neural process responsible for the development of perceptions during exercise.

Physiological disruptions to homeostasis associated with the onset of fatigue appear to influence an individual’s perception of exertion and effort [39, 46]. Therefore, examining the association between varying models or causes of fatigue (i.e. severity, central/mental vs. peripheral) will certainly assist in our understanding of the role of such perception in sport and exercise performance. Such research could incorporate many physiological or psychological manipulations that are known to alter fatigue development (i.e. hypoxia, hyperthermia, physical fatigue, pharmacological administration, deception/placebo, or mental fatigue), which could assist in better understanding possible differences between perceptions of effort and exertion and their role in pacing, fatigue and performance.

Previous experience and memory is believed to be important in the complex integration of the various factors that are ultimately responsible for the perception of effort and exertion [2]. Therefore, an individual’s level of expertise could significantly influence the sensitivity of such measures. Research aimed at examining the sensitivity of perception of effort or exertion across a continuum of ages and fitness levels would provide much-needed information in this area. During such research, consideration should also be given to the sensitivity of the scales used. Indeed, different scales of varying sensitivity (i.e. 6–20, 1–10 or 0–100), and utilizing different anchor points or descriptions, have been developed to monitor perceptions during exercise. As described in Sect. 2, one’s interpretation of any given perceptual scale is likely to depend on the anchor points or terminology used. As such, research examining these anchors in order to determine the most appropriate terminology for various perceptions is warranted. In addition, examination of the Borg scale in comparison to more flexible visual analogue scales could provide insight into this area. However, it should also be noted that since the descriptions and values within a given scale will influence the precise outcome given, the comparison of information across scales is extremely complicated. This has implications in the examination of possible differences and relationships between such perceptions.

5 Conclusions

This review highlights the possible differences between perceptions of effort and exertion. To date, few studies have examined numerous perceptions during exercise, and thus the potential difference, importance and relationship between these variables is not well understood. It appears that perceptions of both exertion and effort are regulated within various regions of the brain based on the integration of information relating to motor drive, afferent feedback and numerous other factors, including prior experience, awareness and motivation. In particular, perceptions of effort may be largely influenced by an efference copy of central motor command which is sent from motor to sensory regions of the brain. Conversely, perceptions of exertion during exercise may be influenced, at least in part, by alterations in afferent feedback associated with disturbances to homeostasis. The relative contributions of afferent feedback, efference copy of motor drive and the integration of this information in the generation of such perceptions is not yet fully understood. Since effort and exertion are both likely to be extremely important in
understanding the underpinning mechanisms influencing the selection of pace, further research monitoring both of these variables during exercise is warranted. Such work may aid in better understanding the complex neural processes that are important in fatigue development and pacing, and during exercise.

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