Commentaries on Viewpoint: Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs

**PERCEPTION OF EFFORT: IT IS WHAT WE THINK WE KNOW THAT KEEPS US FROM LEARNING**

TO THE EDITOR: Perception of effort during dynamic whole body exercise is a subjective interpretation of an integrative signal, which probably resides from peripheral and central mechanisms. Marcora (1) clearly provides arguments that the perception of effort during exercise might be independent from afferent feedback from different systems (cardiovascular, muscular, pulmonary).

Another example that RPE is not only the translation of peripheral input, is when the brain neurotransmission is manipulated during exercise in the heat. We previously showed that when a selective dopamine/noradrenaline reuptake inhibitor is given to cyclist performing in the heat (4), performance on a 30 min time trial significantly improved (9% faster), with core temperatures reaching 40°C or more, without influencing RPE. The “rewarding” effect that might mask the inhibitory signals from the periphery is probably governed by the dopaminergic system in the brain since we also showed in humans that methylphenidate (DA reuptake inhibitor) improved performance on a 30 min time trial by 13% and even increased core temperature more in the 30°C trial without influencing RPE (3). A manipulation of the noradrenergic system did the opposite, i.e., decreasing performance and negatively influencing core temperature (2), with again no difference in RPE between trials.

Homeostatic and non-homeostatic pathways are probably not two completely separate neural systems: significant interactions at different levels might exist; it might therefore be interesting to create transdisciplinary research to advance knowledge. This might help us to think “out of the box” because it is what we think we know that keeps us from learning.

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**COROLLARY DISCHARGES AND PERCEPTION OF EFFORT ARE DISSOCIATED DURING REPEATED SPRINTS**

TO THE EDITOR: The thesis that perception of effort is independent of afferent feedback from skeletal muscles, heart, and lungs (3) during dynamic exercise challenges traditional views. It sustains that corollary discharges resulting from forwarding neural signals solely generate the sense of effort. However, results from studies involving repeated all-out sprints as exercise model raise some questions about this. Mean and peak power generated during 5- to 6-s sprints are decreased while performing 10–20 sprints interspersed by 10–30 s of passive rest (2, 4). This decrease in mechanical output is associated with significant decrease of surface electromyogram amplitude across the sprints (4), which can be linked to the motor neural drive. According to Marcora’s thesis, the perception of effort should be progressively lower, because of the reduction in corollary discharges consequent to diminished muscle activation. It was not confirmed, as the perception of effort increased throughout the repeated sprints protocols (2). Therefore, other sensory cues must influence perception of effort, being multiple and dependent on the individual and task features. We are not precluding here the role of corollary discharges in determining the perception of effort increase during exercise, as during high-intensity continuous ones electromyogram amplitude increases linearly (1) with concomitant RPE increase (5). However, in certain tasks such as repeated sprints it does not seem to be main influence. In conclusion, more research is needed that adds to the understanding of physiological factors that modulate perception of effort in different tasks.

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**TO THE EDITOR:** I am basically supportive of the “Viewpoint” put forward by Marcora (2). However, without wanting to sound high handed, I feel that the approach taken is a little naive. In presenting his case the author wants to restrict consideration to “dynamic whole body exercise” and not include, “isolated and/or isometric exercise.” I am not sure what is meant by this distinction and why the two need to be considered separately. In any case, the author is right in emphasizing the importance of central mechanisms in the generation of the sense of effort. Most of us working in the field of proprioception have long
been aware of such considerations. Previously the view that muscle senses had an entirely peripheral origin was supported by experimental observations (4). At the time it was already appreciated that the senses of effort and of tension were related and included a central component (3). Against this background, recent observations by Gandevia et al. (1) revealed that central mechanisms were able to generate sensations of limb position and probably also movement. The actual interplay between central and peripheral mechanisms during active movements remains problematic and we are looking to principles of robotics in an attempt to obtain an understanding (5). I think Marcora’s conclusion, “that afferent feedback from skeletal muscles, . . . does not contribute significantly to perception of effort” is a little premature. An example of peripheral-central interactions might be the disturbance of the sense of effort by muscle vibration (3).

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TO THE EDITOR: I agree with Dr. Marcora (2) that the sense of effort either rated on a visual analog scale (VAS) or assessed via the traditional Borg rating of perceived exertion (RPE) should represent an evaluation of “the [mental] effort expended in performing a physical activity” rather than a subjective quantification of breathlessness, afferent muscle feedback, or cardiovascular stressing. Furthermore, it is my experience that subjects are capable of making such a rating without referring to so-called muscle pain or any other discomfort that they may experience during exercise (3). I also agree that the perception of effort may increase and even become maximal without alterations in peripheral feedback as demonstrated by studies with curare and hypnotic manipulations (see Refs. 2 and 3). However, I think it is a huge misunderstanding to state that the perception of effort is independent of afferent feedback. Thus several studies support that RPE will increase if peripheral feedback is altered by hypoxia or subjects are exercising with sore muscles (4), whereas RPE may become reduced if muscle pain is relieved by pharmacological manipulations (1) or by attenuation of afferent feedback by endogenous endorphins (5). Therefore, the sensation of fatigue as well as the perception of effort are integrated phenomena and they are both influenced by and dependent of a variety of central and peripheral factors—including afferent feedback from the exercising muscles.

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TO THE EDITOR: Marcora (4) reviewed the evidence that perception of effort during aerobic exercise is independent of afferent feedback. I acknowledge that few people would exclude the necessity for some peripheral feedback for a conscious sensation to be experienced. However, afferent input is not essential for producing the sense of effort as the sensation persists after spinal transection, but it is necessary for calibration of signals of effort (3). The apparent increase in the magnitude of an inspiratory resistive load during partial paralysis of the respiratory muscles is consistent with the hypothesis that estimation of the size of the load depends in part on sensing the size of the outgoing motor command rather than on afferent information signaling the achieved inspiratory flow and force developed (2). However, stimulation of intramuscular receptors and inhibitory feedback to the CNS are being viewed as a dose-dependent trigger of central fatigue (1) to protect the locomotor muscles from excessive peripheral fatigue. The psychobiological model on exercise performance based on Brehm’s motivational intensity theory may provide an alternative to the inhibitory feedback model; exhaustion would occur because subjects are unwilling to invest additional effort rather than because they are physiologically unable to do so (5). I wonder, just as there are gender differences to pain perception, how much do sex and/or age affect sensory psychobiology of perceived exertion? In the end, it seems prudent to conclude that effort likely requires both central stimulation as well as continuous modulation by afferent information from a variety of sources.

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TO THE EDITOR: Marcora (1) suggests “a model popular among physiologists investigating central regulation of exercise performance is that perception of exertion results from the complex integration of different inputs to the CNS.” Given the evidence to date, it may be more in line with current thinking, at least for those investigating central regulation of exercise, if noted that a popular model is that central regulation of exercise results from the complex integration of different inputs to the CNS, one of which is perceived exertion (often used as an index of central command). Although the topic of perceived exertion may be approached from different perspectives (e.g., exercise performance, fatigue, cardiorespiratory regulation, etc.), there is a general understanding that perception of effort can function independent of somatosensory input, in regards to cardiovascular regulation. Morgan et al. (2) used hypnosis to increase the perceived effort of exercise without altering the actual workload and found an increase in cardiovascular responses. Similar studies during both static and dynamic exercise have employed brain mapping to investigate the neural correlates of perceived exertion (3, 4) with related findings from human and animal investigations being reviewed (5). Of note, it is more likely that under normal conditions an exercising individual will take into account the sensations arising from working muscles, breathing frequency, and heart rate, when determining their “perceived” exertion or sense of effort. It is agreed that the specific roles (or contributions) played byafferent input and other neurocognitive processes in setting perception of effort during exercise merit further investigation.

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TO THE EDITOR: Marcora (3) provides a well-articulated review summarizing a substantial number of studies supporting the conclusion that the perception of effort during dynamic whole-body exercise is independent of afferent feedback from small-diameter muscle afferents, heart, and lungs.” It may be instructive to recall Cole and Sedgwick’s study (1) suggesting a role for sensory feedback in recalibrating internal body maps used for motor activity. A prolonged lack of sensory feedback in an individual with a large fiber neuropathy substantially diminished this individual’s ability to sense the effort he applied. While this chronic, long-endured sensory loss provides evidence for a contribution from sensory feedback to the sense of effort, acute experimental losses of sensory feedback, for example by epidural anesthesia (4), strongly support Marcora’s conclusion regarding exercise. But, in addition to chronic and acute losses, discordant sensory feedback may distort internal body maps that presumably influence the corollary discharge of central command. Discordant proprioceptive information has been shown to affect motor imagery (2). In addition, Myer et al.’s study (5), referenced by Marcora, demonstrates that in some individuals a peripherally induced reduction in heart rate increases the perception of effort despite a presumed constant level of central command. Additional investigation during which sensory feedback is made to be inconsistent or contradictory to central command signals may highlight the extent to which the sense of effort is completely independent of feedback during exercise. That the perception of effort during dynamic whole body exercise is entirely and completely independent of afferent feedback is not yet known.

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THE INTEGRATION OF AFFERENT FEEDBACK ON THE PERCEPTION OF EFFORT CANNOT BE DISMISSED

TO THE EDITOR: Marcora (4) rightly stresses the importance of differentiating between ratings of perceived exertion (RPE) (“easy/hard”) and ratings of hedonicity (“good/bad”). Un doubtedly, attempts to quantify the magnitude of exertion are compromised if instructions confuse perceptions of “affect” with perceptions of “effort,” when interpreting sensations from the working muscles and lungs. These constructs have been applied independently and successfully to regulate exercise intensity (3, 5). The statement that RPE is “independent of afferent feedback from the skeletal muscles, heart, and lungs” is perhaps deliberately provocative, but it is hard to accept in its entirety. Outside the laboratory, the exerciser regulates intensity by assimilating the combined sensations and feedback arising from muscular contraction, heart rate and the rate and depth of breathing (for whole body endurance tasks). The interpretation and regulation of exercise intensity through the RPE is dependent on the integration of these somatosensory signals and neurocognitive mechanisms. In the latter regard, key factors include age, cognitive ability, environment, experience, knowledge of exertional cues across the intensity spectrum, and knowledge of the end point (2). Afferent feedback plays a role in a number of these. Furthermore, current research indicates that the higher RPE following eccentric exercise may be due, in part, to the enhanced ventilatory response that accompanies the increased muscle soreness (1). This is attrib-
ued to the distension of blood vessels, which provokes a discharge from the group III and IV afferent fibers that leads to an increase in ventilation. The integration of afferent feedback on RPE therefore cannot be dismissed.

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TO THE EDITOR: Marcora (3) correctly points to the complexity of the integrative process resulting in effort perception. Effort perception during exercise arises from the comparison of the demands from a feedforward center that is shaped by psychological (e.g., mood, anxiety, etc.) and cognitive and contextual factors (e.g., prior experience at a given level of effort and performance setting) and from physiological, biomechanical, visual, and auditory sensory information. This information is preconsciously processed along with the affective dimension of exertion. This preconsciously processing selectively filters the information that rises to conscious awareness, leading to effort perception from which conscious decisions with regard to continuing exercise are made—this process is termed teleoanticipation (2).

A distractive stimulus (e.g., music) can reduce perception of exercise effort. This hypothesis, based on Rejeski’s parallel information model (4), proposes that limited attentional channels permitting preconscious content to become conscious results in only some of this information reaching conscious perception. If sufficient effort-related elements reach consciousness, the condition is interpreted as having a high RPE score. Flooding the preconscious with distractive stimuli (e.g., music) reduces the amount of information that can reach consciousness, thus reducing the sense of effort (1, 5). Promoting attention to the external environment reduces awareness of physiological sensations and negative emotions, thus minimizing the perception of effort. Conversely, screening out distracting external information via visual/auditory deprivation directs attention to internal processes, intensifying the sense of effort.

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THE PERCEPTION OF EFFORT: MIND OVER MUSCLE?
TO THE EDITOR: The concept that the perception of effort (i.e., effort sense) during exercise is not determined by sensory information from peripheral and visceral organs but rather by the conscious awareness of central motor commands is generally supported by the work highlighted by Marcora (1). Indeed, similar conclusions may be drawn from studies in which effort sense has been manipulated by hypnotic suggestion (2, 3). For example, during constant-load cycling (e.g., peripheral and visceral afferent input remains relatively constant), the suggestion that one is cycling downhill has been shown to decrease an individual’s rating of perceived exertion (RPE) while suggesting uphill cycling increases this rating (3). In addition, just imagining handgrip exercise has been shown to increase RPE almost to the same level as when exercise is actually performed (2). Under these unique experimental conditions, the perception of effort appears to be independent of feedback from skeletal muscle, heart, and lungs. In contrast, electrically induced exercise (i.e., no central motor command input) in patients with a hemisection of the spinal cord (Brown-Sequard syndrome) elicits larger increases in RPE when a leg with intact sensation is stimulated as compared to a leg with a sensory deficit (4). These data suggest that sensory input from skeletal muscle maintains the potential to modulate effort sense. As the performance of exercise requires the integration of multiple systems, it is likely that the perception of effort is determined by inputs both central and peripheral in origin.

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