Sense of effort and other unpleasant sensations during exercise: clarifying concepts and mechanisms

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ABSTRACT

Introduction The sense of effort is an essential component of all forms of exercise. Although extensively studied, exercise physiologists have failed to reach consensus about whether this sensation is based on afferent sensory feedback or is centrally generated and independent of such feedback. This confusion has led to misunderstandings regarding the neurological mechanisms responsible for the sense of effort as opposed to other specific sensations such as pain and temperature.

Discussion A mechanism in which the sense of effort is centrally generated and independent of feedback had been proposed more than 150 years ago. However, a more recent concept of sense of effort as a subjective rating of exercise intensity based on various sensations experienced during exercise given by Borg may have caused confusion, especially among exercise physiologists. Many began to use and understand the sense of effort as a sensation that is generated by afferent sensory feedback. The information reviewed in this article, together with the examples given, constitutes a body of evidence in favour of a centrally generated sense of effort. Afferent sensory feedback is important for the conscious awareness of different sensations such as pain and temperature, and plays important roles in the control of homeostasis. However, peripheral sensory feedback does not seem to be important for the generation of the sense of effort.

Conclusion The sense of effort and other specific sensations such as temperature, pain and other muscular sensations present two separate neurological mechanisms. While the former is centrally generated, the latter is based on afferent sensory feedback. An interaction of these sensations is likely the ultimate regulator of exercise performance. However, further investigation is required to fully understand these phenomena.

A recent issue of this journal highlighted the topic of pacing and performance.[1] As has previously been suggested,[2 3] the studies included in this issue[4–6] showed that the sense of effort is a key feature not only for pacing strategy but also for limiting the exercise performance. It is worth mentioning that the importance of the sensations during exercise had been emphasised by Lehmann and colleagues more than 70 years ago, as highlighted by Ikai and Steinhaus[7]: 'the end point of any performance is never an absolute fixed point but rather is when the sum of all negative factors such as fatigue and muscle pain are felt more strongly than the positive factors of motivation and will power.' Thus, because the sense of effort is such an imperative element during exercise, it is important to seek a complete understanding of this sensation. Exercise physiologists have failed to reach consensus concerning the mechanisms underpinning the sense of effort. A common view among exercise physiologists is that afferent feedback is a major contributor to the sense of effort.[3 8] However, it has recently been suggested that the sense of effort is, in fact, centrally generated and independent of afferent feedback.[9 10] This idea has evoked many different opinions.[11] This uncertainty may arise partly from confusion about the concept behind the sensation measured by the famous 'Ratings of Perceived Exertion' scale. This has led to misunderstandings regarding the mechanisms responsible for the sense of effort as opposed to other specific sensations such as pain and temperature. In order to advance the field, it is important to identify the historical origin of the confusion and to clarify the difference between the sense of effort, other specific sensations and their likely mechanisms.

PROBLEM IDENTIFICATION

Theories regarding the sense of effort (or, as originally named, sensation of innervation) have been presented as early as the 19th century by physiologists and psychologists such as Helmholtz and Wundt.[12] They believed that voluntary actions would produce sensations that arise wholly within the brain, independent of afferent information from the activated muscles.[12] Although extensively debated, the original concept of the term sense of effort is not always properly used, causing misunderstandings.[11] In contrast to the original concept of the term, the sense of effort has also been used to describe the integration of sensations originating from peripheral organs.[3 8]

This confusion may have its origin approximately 40 years ago. In 1970, Gunnar Borg[13] proposed a scale called the 'Ratings of Perceived Exertion' (updated in 1985[14]) to quantify a subjective feeling that would represent the sensation originated from the sum of all the bodily systems during exercise.[13 15] The use of this scale has become enormously popular.[16] The term 'perceived exertion' was subsequently interpreted worldwide according to Borg's concept: '…integrates various information, including the many signals elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions, and from the central nervous system.'[15] Although the appropriate verbal anchors chosen by Borg to his scale (light/hard), his widespread interpretation of the term sense of effort (above quoted) has led some researchers to describe this sensation as formed on the basis of afferent sensory information, and the original concept of the sense of effort as a centrally generated sensation has been 'forgotten.'

SENSE OF EFFORT

More than 150 years ago, researchers believed that motor areas in the brain would directly influence sensory areas, producing sensations independently of afferent sensory feedback (see figure 1 in Ross and Bischof[12]). A similar mechanism through which motor commands would provide information to sensory areas about the consequences of a movement was also proposed to explain the experiments carried out by Sperry[17] and von Holst and Mittelstaedt (see Feinberg[18]) in 1950. The terms proposed by these latter authors (ie, corollary discharge and efference copy, respectively) have been used to describe this motor forward command during voluntary movements,[19] and the interaction between motor commands and sensory signals has been specifically studied in both animals and humans.[20–23]

Special focus on the association between central commands and the generation of the sense of effort has been made possible, especially by weight discrimination studies.[24] Gandevia and McCloskey showed that, although weight discrimination needs at least a crude peripheral signal,[25] the sensation of heaviness is influenced mainly by the centrally generated sense of effort.[26] In addition, the blocking of activity in the ascending sensory pathways of the lower limbs during cycling produced a higher, instead of lower, mean sense of effort over a 5 km time trial when compared with control. This was despite both having the same mean power output.[27] Further, studies have shown that sense of effort can be changed despite no metabolic stress.[28 29] However, the debate as to whether the sense of effort is generated solely based on motor commands merits further investigation. Activity in the corticofugal paths[30] and influence from neural centres upstream of the motor cortex[31] may also play a role in its generation.

Recent investigations have advanced our understanding of the mechanisms involved in this forward model during voluntary movements. Christensen *et al*[32] have concluded that the premotor cortex modulates the primary somatosensory cortex via efference copy, irrespective of sensory feedback. Using direct electrical stimulation to the brain, Desmurget *et al*[33] (see also Haggard[34]) found that the supplementary motor area is closely related to motor commands, whereas the parietal cortex is involved in the sensory predictions of the movements. The findings of Wolpert *et al*,[35] which showed that parietal lesions impair both the sensory and the motor systems, strengthen the hypothesis that the parietal cortex is crucial for the forward model during voluntary movements.

Therefore, the information presented here, combined with the studies reviewed by Marcora[9 10] and other commentators,[11] constitutes a body of evidence in favour of a centrally generated sense of effort.

OTHER SPECIFIC SENSATIONS

Claude Bernard's concept of homeostasis has been summarised by Woods and Ramsay as: the various organ systems were viewed as having the capacity to counter harmful deviations in one or another variable in the service of guaranteeing a relatively stable and benevolent milieu intérieur.'[36] Homeostatic control of the 'milieu intérieur' requires afferent feedback in order to allow neural processes to maintain physiological balance. I support the previous opinion[37] that the most remarkable feature of human homeostatic control is our capacity of awareness of multiple bodily conditions that, when integrated with our emotional and cognitive states, produces more appropriate behavioural decisions.

Recently, Craig[38 39] defined the concept of interoception as a novel approach to understand the human perception of 'feelings' from the entire body. He proposed an afferent pathway that conveys signals from small-diameter primary afferents, thereby transmitting information on the physiological status from all tissues in the body (temperature, pain, muscular and visceral sensations, etc) to specific sites in the brain. This pathway represents a key component for homeostatic control. Additionally, brain regions involved in the regulation of internal bodily conditions seem to be related to the process of feeling emotions,[40] which further enhance the capacity to maintain homeostasis. Craig[41] also reviewed more recent evidence regarding the awareness of subjective feelings and proposed that the anterior insular cortex is the main brain site responsible for the awareness of feelings from the body, and that this structure is linked to the anterior cingulate cortex which, in its turn, is responsible for the initiation of behaviours.

In light of these studies, it is possible to conclude that the conscious awareness of different sensations such as temperature, pain and other muscular sensations is part of the body's homeostatic control, which may act to improve behavioural decisions during exercise on the basis of afferent sensory feedback. However, the literature lacks definitive evidence on how important these sensations are during exercise in order to have a significant influence on performance tolerance.

PRACTICAL EXAMPLES

Although probably presenting similar responses during common exercises such as continuous running or cycling, it is possible to notice that the sense of effort and other unpleasant sensations are clearly disassociated in various situations. A short maximal voluntary contraction for leg extension, for example, will by nature induce a maximal sense of effort while, initially, other unpleasant sensations will probably be modest. Repeating this maximal contraction several times, however, will increase these unpleasant sensations continuously, whereas the sense of effort will be always the same (ie, maximal). Another example is a marathon runner who, after contending head-to-head with an opponent, finishes the race. In the last metres, his/her sense of effort and other unpleasant sensations would be near to maximal. Just after finishing the marathon, however, despite still feeling many unpleasant sensations, his/her sense of effort would be dramatically reduced, while the only current effort expended would be to maintain the upright posture and the breathing. A last example is a cyclist who, after an uphill section, suddenly starts a downhill section and stops pedalling, going down solely with his own momentum. Although still feeling highly unpleasant sensations due to the uphill climbing, the effort expended to go down the downhill is virtually zero, which means a very low sense of effort.

The decision to measure either the sense of effort or other specific sensations during studies may vary according to the particular research aims. The instructions provided by the researchers to the subjects are crucial in order to determine which of these outcomes will be measured, as also highlighted by Marcora.[9]

CONCLUSION

After the review of the various studies presented here, together with the examples given, it is possible to conclude that two separate neurological mechanisms produce the sense of effort and other specific sensations such as temperature, pain and other muscular sensations. It is important to note, however, that although the mechanism of awareness of the sense of effort appears to be centrally generated, constant feedback from the whole body is continuously monitored and likely plays a role in the conscious regulation of the effort applied during each moment of a task. Despite the need for further research to determine how important they are, the fine line between the willingness to continue exercising and the decision to stop is probably influenced by an interaction of both sense of effort and other unpleasant sensations. Thus, despite having different neurological mechanisms, the sense of effort and other unpleasant sensations appear to be closely related during most exercises. Still, further investigation is needed to fully understand these phenomena.

With the natural progression of science, questions arise: how do the sense of effort and other unpleasant sensations interact during exercise? Which one is the most important for the decision to reduce the chosen intensity or even to stop exercising?

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What is already known on this topic

Exercise physiologists have failed to reach consensus about whether the sense of effort is based on afferent sensory feedback or it is centrally generated and independent of peripheral sensory feedback.

What this study adds

- The uncertainty about these mechanisms in the current literature may be explained by the widespread global acceptance of the 'Ratings of Perceived Exertion' scale and the popular interpretation of the term sense of effort given by Borg.
- The review of several studies produces a body of evidence which suggests that the sense of effort and other specific sensations such as pain and temperature present two separate neurological mechanisms. While the sense of effort is centrally generated and seems to be independent of peripheral feedback, the latter is based on afferent sensory feedback.

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