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review article

Evolution of perceived exertion concepts and mechanisms: a literature review

Evolução dos conceitos e mecanismos da percepção de esforço: uma revisão de literatura

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Abstract – The mechanisms and concepts of perceived exertion have changed over the years. Thus, the objectives of the present literature review were i) to investigate the literature reviews that have been published since 1982 and to describe the proposed causal mechanisms of perceived exertion, and ii) to determine whether the concepts of perceived exertion have accompanied the changes of its proposed mechanisms. Searches were performed in PubMed, Science Direct and Scielo using the terms 'rating of perceived exertion and review' and 'perceived exertion and review'. Eighteen papers whose main objective was to determine the overall perceived exertion during physical exercise were included in the present study. It was observed that, despite the existence of the early corollary discharge theory, after Borg's propositions most of the literature has explained perceived exertion using the afferent feedback theory based on correlational studies. It was only in 2009 that there was a resurgence of the original corollary discharge theory in perceived exertion papers. Most of the perceived exertion concepts are related to the afferent feedback mechanism, using constructs such as physiological responses, stress, discomfort and pain. However, these constructs are incongruent with the corollary discharge theory, presenting physiological mechanisms that differ from those of perceived exertion. Therefore, Borg's studies have influenced contemporary views of the mechanisms and concepts of perceived exertion. Over the years, additional constructs have been incorporated into the original Borg's concept, although always on the basis of the afferent feedback theory.

Key words: Motor activity; Muscle fatigue; Physical exertion.

Resumo – *Os mecanismos e conceitos da percepção de esforço têm mudado ao longo do tempo. Assim, este artigo de revisão de literatura tem por objetivos: i) investigar as revisões de literatura publicadas a partir de 1982, descrevendo os mecanismos causais de geração da percepção de esforço relatados e; ii) verificar se os conceitos da percepção de esforço acompanharam as mudanças que ocorreram acerca dos seus mecanismos causais. Foram realizadas buscas nas bases de dados PubMed, Science Direct e Scielo com os termos "rate perceivedexertionandreview" e "perceivedexertionandreview". No total, foram incluídos 18 artigos, que tiveram como objetivo principal a percepção geral de esforço em exercício físico. Apesar da antiga existência da teoria do Disparo corolário para explicar os mecanismos causais da percepção de esforço, verifica-se que, após as proposições de Borg, a maior parte da literatura descreve a percepção de esforço através do mecanismo de Feedback aferente, baseada em estudos correlacionais. Apenas em 2009, a teoria original do Disparo corolário reaparece. Quanto aos conceitos, a maioria deles remete ao mecanismo de feedback aferente, utilizando-se de constructos como respostas fisiológicas, estresse, desconforto e dor, que são incongruentes com a teoria do Disparo corolário e apresentam mecanismos distintos aos da percepção de esforço. Portanto, verificou-se que os estudos de Borg influenciaram nos mecanismos e conceitos contemporâneos da percepção de esforço. Com o passar do tempo, houve incorporação de constructos no conceito original de Borg, porém, sempre embasado na teoria do Feedback aferente.*

Palavras-chave: *Atividade motora; Esforço físico; Fadiga muscular.*

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INTRODUCTION

Rating of perceived exertion (RPE) is a widely known psychophysiological measure that is extensively used in the areas of sports and rehabilitation and investigated in the scientific field. Its applications involve monitoring during physical stress tests, prescription of exercise intensity, acute and chronic monitoring of training loads, and the prediction of maximum exercise capacity[1-4]. For a correct application of RPE, it is important to understand its meaning and to identify its origin and nature. It is essential to investigate the complex psychophysiological mechanisms that give origin to RPE since its psychobiology is directly interlinked with its applications. Efforts in this respect are not recent, since this phenomenon has been studied since the 19th century[5], although to date there is no unified theory explaining the mechanism of control and perception of effort, especially review studies that provide state of the art updates.

A theory that attracted considerable attention on the part of researchers in the 1980's considered RPE to be generated by the brain with little or no participation of afferent feedback information from peripheral systems[6-8]. This theory, called corollary discharge (or efference copy), proposes that RPE is generated by the motor command sent from the brain to the muscles, with a "copy" or "irradiation" being concomitantly sent to sensory brain areas, resulting in RPE.

However, a theory frequently adopted today by researchers is afferent feedback. According to this theory, RPE is mainly generated from afferent information of peripheral systems which is transmitted to the brain[9,10]. In this theory, the cardiorespiratory, muscular and metabolic systems are seen jointly as the primary causes of the information that leads to the generation of RPE[11].

As suggested in a previous publication[12], this change in the current paradigm regarding the mechanisms proposed for the generation of RPE may have been strongly influenced by the studies of Gunnar Borg[13,14]. Borg started his studies on RPE in the 1970 decade[14] and published a widely known scale for the measurement of RPE in 1982[15]. This scale is frequently used during physical exercise, with the subject being instructed to express verbally a numerical value for his RPE with the help of text descriptors located along the scale. Over the years, the use of both the RPE scale and the mechanism proposed by Borg[15] has spread all over the world.

Another relevant aspect in scientific research is the concept of the phenomenon that is being investigated. Precise instructions given to the participants by the investigators regarding the concept under study define the theoretical model to be used in the explanation of the results. For example, the sensations of "temperature" and "pain" are based on neurophysiological mechanisms differing from the sensation of effort[12] and, when the participants are instructed correctly they are able to identify these distinctions during exercise[16]. Thus, when using the concept of RPE as *"effort expended when performing a physical activity"*[17], pain and

temperature sensations may not be reported by the exercising individual and consequently the theoretical model for explaining the results should be the corollary discharge. In contrast, the use of the definition as *"stress, pain and fatigue involving the muscles and the cardiovascular and respiratory systems during exercise"*[18] would inevitably refer to the theory of afferent feedback. Thus, concepts that are inconsistent with theoretical models may perpetuate equivocal conclusions, delaying the progress of scientific knowledge about a given phenomenon or study area.

Based on the above considerations, the objective of the present review article was to investigate review articles published in the literature since 1982, thus describing the mechanisms proposed for the generation of RPE. An additional objective was to determine whether the concepts of RPE have accompanied the changes that have occurred regarding its causative mechanisms.

METHODOLOGICAL PROCEDURES

Only review articles were included in the present narrative survey. This criterion was adopted because articles of this nature are good descriptors of the generalized data presented in analytical studies during a given period. Papers published between 1982 and July 2013 were selected. The search terms used were "*rating perceived exertion and review*" and "*perceived exertion and review*". The databases used were PubMed, Science Direct and Scielo. Inclusion criteria were: 1) review articles, 2) papers published in English, and 3) papers whose main objective was to deal with general RPE during physical exercise.

A total of 220 review articles were detected. After papers appearing in more than one database and papers whose title did not agree with the objective of the present review were excluded, a total of 116 papers were left. A reading of their abstracts narrowed down the choice to 30 papers for full reading, with a final selection of 18 papers for inclusion in the present review (Figure 1). The excluded articles were those focusing on local subjective perceptions (e.g. upper or lower limbs, and breathing) rather than on general RPE.

RESULTS

The 18 articles representing the final result of the literature review are listed in Box 1. It can be seen that five review articles were published in the 1980 decade, three of them in the same year as the important article of Borg[15] (1982). In the 1990 decade, the number of publications of this nature increased to seven, an increase that may be explained by the increased number of experimental papers using RPE, mainly due to the marked applicability of RPE to different contexts related to physical exercise and to its association with diverse physiological variables. Four articles mainly focusing on the physiological mechanisms that regulate RPE were published in the

subsequent decade. A similar objective was detected in the only two articles published in the current decade. Finally, it can be seen that only 61% of the articles selected (n = 11 of 18) presented a conceptual description of RPE.

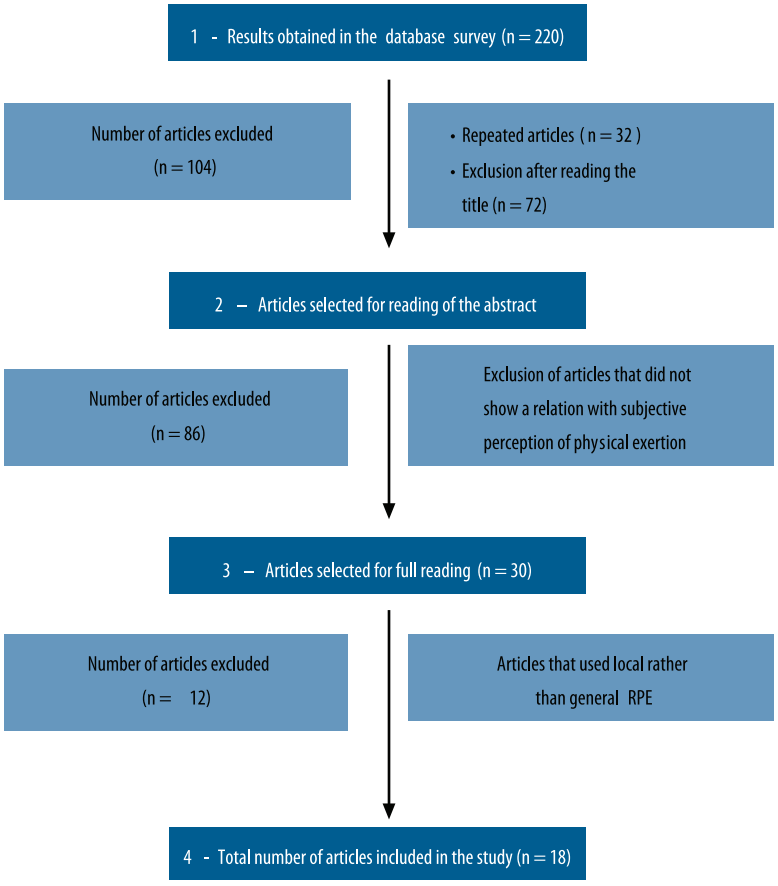

Figure 1. Flow diagram of the selection of review articles published in the literature.

Box 1. Review articles published between 1982 and July 2013 listed according to the decade of publication, with their respective concepts and mechanisms of subjective perceived exertion.

Reference	Concept	Mechanism
	1980 to 1989	
Borg[15]	Indicator of the degree of physical stress	Various inputs are integrated, including the various signals sent from the periphery by active muscles and joints, from the central functions of the cardiovascular and respiratory systems, and from the central nervous system
Cafarelli[19]	The effort of any brief dynamic or static contraction is probably perceived as force. Exertion is defined as the degree of difficulty felt during exercise	Three possible mechanisms: 1-Feedforward: a copy of the central motor signal is sent directly to the sensory cortex; 2-Feedback: afferent signals from sensory receptors to the cortex; 3-Feedforward + feedback: expected and real results of muscle contraction are compared and continuously adjusted
Robertson et al.[20]		Multifactorial response including signals originating a) from the sensory functions of mechanoreceptors, baroreceptors and chemoreceptors; b) specific physiological response to exercise, and/or c) responses of efferent copies involving regulation of the central nervous system or integration with various physiological adjustments during exercise

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Reference	Concept	Mechanism
O'Sullivan[21]	Subjective perception of the intensity of physical work	1-Local: pains, cramps, discomfort, fatigue and stress in the muscles, tendons and joints; 2-Central: circulatory, respiratory and metabolic responses; 3-Psychological factors
Carton et al.[22]		1-Local factors: blood and muscle lactate, adenosine triphosphate and glycogen; 2-Central factors: heart rate, ventilation and oxygen consumption; 3-Non-physiological factors: time of day, sleep deprivation, depressive state, gender, environment, type and duration of exercise
	1990 to 1999	
Bruce et al.[23]		1-Local factors: sensations originating from the musculature and active joints; 2-Central factors: sensations originating from the cardiorespiratory system; 3-psychological factors
Dishman[24]	A subjective organization of the sensory information associated with various physiological responses to exercise	Local factors control RPE during low-intensity exercise. However, with increasing intensity, central factors such as sensations associated with increased blood lactate concentration and hyperventilation become predominant
Morgan[25]	It is a separate or distinct sensation and a psychophysiological construct that represents the integration of multiple sensory signals	It is a configuration of sensory signals in syntony with various types of physiological and psychological responses, as well as past experiences. RPE during physical exercise is determined by the intensity of exercise and by individual factors such as gender, personality and training status
Sanes et al.[26]		Efferent copies cannot be fully responsible for the conscious interpretation of muscle exertion; thus, there must be an alternative mechanism such as somatic afferent sensory information originating at the periphery
Robertson et al.[2]	Subjective intensity of exertion, stress, discomfort, and/or fatigue experienced during physical exercise	An organized response that incorporates information from internal (physiological and psychological) and external environmental factors
Russel[27]	Objective representation of the physical exercise that is being performed	A complex interaction of cognitive, affective and perception factors that operate during physical exercise
Robertson et al.[3]	Subjective intensity of exertion, stress, discomfort, and/or fatigue experienced during physical exercise	Perceptive signals are partially supplied by physiological mechanisms (signals originating from the respiratory and metabolic systems and from skeletal muscle), in combination with organic responses induced by exercise stress
	2000 to 2009	
Groslambert et al.[18]	A configuration of sensations: stress, pain and fatigue involving the muscles and the cardiovascular and respiratory systems during exercise	Derived from cardiorespiratory factors (heart rate, oxygen consumption, respiratory rate and minute ventilation) or peripheral factors (blood lactate concentration, blood pH, mechanical stress, skin and central temperature)
Gibson[28]		Derived from afferent information during exercise, from previous experience of a similar exercise, and from the psychological status of the individual
Marcora[17]	Exertion applied during physical activity	Conscious perception of the central motor command to the muscles involved in locomotion and respiration.
Tucker[10]		Afferent feedback from the various physiological systems give origin to conscious RPE
	2010 to 07/2013	
Eston[4]	How difficult or easy exercise is perceived to be at any particular time	This involves a collective integration of afferent feedback from cardiorespiratory, metabolic and thermal mechanisms and from feedforward. RPE is moderated by psychological factors (cognition and memory) and by situational factors (duration and awareness of the end of the task)
Smirmaul[12]		Centrally generated through motor areas in the brain that directly influence the sensory areas by efferent copy

DISCUSSION

In his most influential publication, Borg stated that RPE "*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]. This causal mechanism of RPE proposed by Borg[15] (denoted afferent feedback theory) was based on investigations that detected high correlations between RPE and heart rate and oxygen consumption[15], in addition to other physiological variables[29]. Thus, since the higher the heart rate (and oxygen consumption), the higher the RPE reported by the subjects, the authors concluded that the relationship between these variables was causal. As mentioned here in the introduction, investigations preceding the study of Borg[15] presented a different theory as the cause of RPE. Those studies were mainly based on investigations involving local anesthesia (affecting afferent feedback information) and the paradigm of correspondence of the contralateral limb, whereby the perceptions of estimated and performed strength and exertion were compared between a fatigued and a non-fatigued limb[6-8]. In his study of greatest impact, Borg did not consider these theories[15]. Thus, the afferent feedback theory was originally proposed on the basis of correlational studies which only identified a statistically significant association between two or more variables, with no experimental evidence confirming the hypothesis of afferent feedback as the cause of RPE.

From 1982 to 2008, only three review articles recognized the possibility of the corollary Discharge theory. Two of these reviews were published in the same journal and in the same issue as the 1982 study by Borg[15,19,20]. It can be seen, however, that most of the review studies published after 1982 (n = 15 of 18) used the afferent feedback theory or a similar one when explaining the causal mechanisms of RPE. Over the years, various types of physiological information transmitted by afferent pathways have been proposed to give origin to RPE, such as pains, cramps, fatigue, muscle stress, lactate, glycogen, heart rate, and ventilation, among others. This fact suggests that the mechanisms proposed by Borg[15] strongly influenced his contemporary authors even though the evidence only came from correlational studies, indicating the absence of questioning about the origin of this construct.

More recently, in 2009, the "forgotten" corollary discharge theory resurfaced on the scenario of discussion of the mechanisms of RPE[17]. In his study, Samuele Marcora[17] reviewed various articles involving experimental manipulations that dissociated RPE from the afferent feedback originating from the muscular, respiratory and cardiovascular systems. In addition, in 2012, based on a review of various evidence, Smirmaul[12] concluded that RPE and other sensations such as pain and temperature, for example, have different neurophysiological mechanisms, with the former being mainly based on the corollary discharge theory and the latter on the afferent feedback theory.

However, although the influence of signals originating from afferent feedback has not been fully ruled out[30], it is important to point out that, even though most of the reviews reported here adopt the afferent feedback theory, several original articles using different methodologies refute this theory and support the corollary discharge theory to explain the causal mechanisms of RPE[12,17].

The concept of perceived exertion has been discussed scientifically by physiologists and psychologists since the 19th century[16]. Mainly after the publications of Borg[13-15] and the consequent increased use of the RPE scale in the scientific milieu, review studies started to be published looking for a better understanding and conceptualization of the perceived exertion construct and of the use of the RPE scale[2]. However, the concept of RPE is presented in different manners among the studies, also differing from the concept originally proposed by Borg[15], a fact that usually leads to equivocal assessments, interpretations and uses of theories.

In 1982, Borg conceptualized RPE as *"an indicator of the degree of physical stress"*[15]. Subsequent review articles used varied concepts for RPE, although most of them involve constructs such as sensory information associated with various physiological responses[24]; integration of multiple types of sensory information[25]; stress, discomfort and/or fatigue[2]; stress, pains and fatigue involving muscles and the cardiovascular and pulmonary systems[18]. All of these concepts are integrated in the causal mechanism of RPE proposed by the authors which, in this case, is the afferent feedback theory.

Marcora[17] suggested that the mechanism of RPE used by most authors derives from an equivocal conceptualization of RPE. When individuals are instructed to report sensations such as "discomfort" and "pain", for example, constructs differing from that of effort will be measured[16]. Indeed, unpleasant sensations such as increased pain and temperature, for example, are based on neurophysiological mechanisms that differ from effort mechanisms[12]. Thus, Marcora[17] conceptualizes RPE as *"the effort expended in performing a physical activity"*, using the corollary discharge model to describe its mechanisms of origin, as determined in previous experimental studies[12,17].

Based on the analysis of the evolution of concepts and mechanisms of RPE, by examining literature reviews we identified two main aspects that transcend the phenomenon studied here and apply to other study areas. We first identified that the construction of knowledge about RPE started in 1982 without due consideration of previously acquired scientific evidence. In this case, we refer to the corollary discharge theory that was elaborated before the mechanism of RPE regulation proposed by Borg in 1982, and that was rescued in 2009[17]. Learning about the historical evolution of a determined study area contributes not only to avoiding reproductions, but also to a better delineation of the methods used. The second point identified in the present review was that in several studies the associations between physiological variables and RPE were interpreted to involve a causal relationship,

a fact that was not always correct. For example, positive and significant correlations between RPE and heart rate do not necessarily indicate that a higher heart rate causes an increase in RPE.

We would like to emphasize, in addition to the factors discussed above, an important methodological aspect of the present study, i.e., that only review studies were considered to be eligible for analysis. This option was due to the fact that, logistically, it would have been unviable to review all the original articles that included the RPE variable in their analyses. In addition, there is an enormous diversity of approaches to RPE in each of these original papers and summarizing all of these aspects was beyond the scope of the present study. We are aware of the fact that other literature reports approach RPE in different manners compared to those described in the present study; however, these reports are not review articles. In contrast, review studies usually involve a broader discussion of the RPE variable and therefore were more appropriate in terms of the objectives of the present study.

FINAL COMMENTS

The present review demonstrated that there is a predominance of the afferent feedback model in the literature in order to explain the causal mechanisms of RPE during physical exercise, especially after the influential publication of Borg[15], although there are only correlational indications. Despite the notoriety of the corollary discharge theory in the 1980's in order to explain the causal mechanisms of RPE, this theory was not mentioned in most of the review articles published up to 2009, when two such publications rescued it. It was observed that most of the concepts encountered involve constructs such as physiological responses, stress, discomfort and pain which do not agree with the theory of corollary discharge and that present mechanisms differing from those of RPE.

Thus, the study by Borg[15] was shown to influence the contemporary mechanisms and concepts of RPE. On this basis, it is essential to identify the real causative mechanisms of RPE since the interpretation of the results and their applications are directly interlinked with its psychobiology.

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