The psychobiological model: a new explanation to intensity regulation and (in)tolerance in endurance exercise

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Abstract

The mechanisms underpinning fatigue and exhaustion, and the specific sources of exercise-endurance intensity regulation and (in)tolerance have been investigated for over a century. Although several scientific theories are currently available, over the past five years a new framework called Psychobiological model has been proposed. This model gives greater attention to perceptual and motivational factors than its antecedents, and their respective influence on the conscious process of decision-making and behavioral regulation. In this review we present experimental evidences and summarize the key points of the Psychobiological model to explain intensity regulation and (in)tolerance in endurance exercise. Still, we discuss how the Psychobiological model explains training-induced adaptations related to improvements in performance, experimental manipulations, its predictions, and propose future directions for this investigative area. The Psychobiological model may give a new perspective to the results already published in the literature, helping scientists to better guide their research problems, as well as to analyze and interpret new findings more accurately.

Key words: Exercise performance; Fatigue; Perception of effort.

Introduction

Exhaustion and fatigue are two phenomena intrinsically associated to exercise performance. Exhaustion can be defined as the inability to maintain the required physical task[1]. On the other hand, fatigue consists of a process leading to an exercise-induced reduction in the maximal force capacity of the muscle[2]. Mechanisms underpinning fatigue and exhaustion during exercise have been extensively investigated for over a century. The reasons for such attention are the wide implications in our daily life. For instance, fatigue and exhaustion can impair quality of life in chronically or acutely ill patients, constrain performance in occupational duties (e.g., firefighting, military, etc) and influence on exercise participation and sports industry[3]. Furthermore, both phenomena are of paramount importance during exercise, once they are the specific sources of exercise intensity regulation and exercise (in)tolerance.

Several scientific theories are currently available to explain intensity regulation and (in)tolerance in endurance exercise (for a review refer to Abiss & Laursen[4]). Two of the main existing theories are named Central Governor model[5, 6] and Inhibitory Feedback model[7,8]. However, over the past five years, a new framework called Psychobiological model has been proposed by Samuele Marcora and colleagues[9-16]. The scientific community seldom acknowledges this theory so far, probably because it involves constructs that are not well accepted by both classical and modern physiologists. For instance, a recent published paper discussed the regulation of pacing strategies to exercise-endurance performance under only one framework, i.e., the Central Governor model[17].

The Central Governor and the Inhibitory Feedback models are strongly based on physiological, reflexes and subconscious constructs to explain exercise performance regulation and limitation in humans. These models attribute negligible importance to the role of psychological factors as exercise performance modulator, excepting recent formulations of the Central Govern model that included ad hoc psychological explanations as the model evolved[6,18]. However, the importance of the psychological factor to modulate performance has been reported since the 60ths[19].

Hence, the Psychobiological model gives greater attention to perceptual and motivational factors, and their respective influence on the conscious process of decision-making and behavioral regulation. In addition, this model explains exhaustion based on the psychological exercise (in)tolerance, while the Central Governor and Inhibitory Feedback models explain these phenomena based on subconscious and anticipatory process (i.e., not subject to willingness), or physiological inability (i.e., physiological limit). Some of these constructs are not empirically testable yet, thereby providing a shield against refutation.

The predictive and explanatory differences among the models to account for fatigue and exhaustion in endurance exercise have led to an increased number of publications with different experimental designs, in which most of the results interpretations have relied on the Central Governor and Inhibitory Feedback models. However, the theoretical background of the Psychobiological model for endurance-exercise (in)tolerance have not been summarized to date, and may help to give a new perspective for the results that have already been published. In addition, the increasingly widespread discussion of this topic can help scientists to better guide their research problems, as well as to analyze and interpret new findings more accurately. Therefore, the aim of this review is to present experimental evidences and to summarize the key points of the Psychobiological model to explain intensity regulation and (in)tolerance in endurance exercise.

The basis of the Psychobiological model

The Psychobiological model is based on the Brehm's Motivational Intensity Theory[20,21], which consists of two main constructs: potential motivation and motivation intensity. Potential motivation refers to the maximum effort a person is willing to exert to satisfy a motive (e.g., to succeed in the exercise task), while motivation intensity is the amount of effort that people actually expend[21]. The Brehm's Motivational Intensity Theory postulates that individuals will engage in a task (i.e., exert effort) as long as: a) the level of potential motivation is not reached; or b) the task is still viewed as possible. If the former is reached or the task is perceived as impossible, individuals should disengage from the task[21]. In the light of the Psychobiological model, the point of exhaustion during exercise is a form of task disengagement, in which individuals will exercise until a) the perception of effort raises to the critical level set by the potential motivation; or b) believe to be physically unable to maintain the task. In the latter case, they believed to have exerted a true maximal effort, and the continuation of exercise is perceived as impossible[14]. The Psychobiological model still predicts that an increase in exercise tolerance should occur either when the potential motivation is increased or when perception of effort (defined as the conscious sensation of how hard, heavy, and strenuous a physical task is[22]) is reduced. In this situation, any other factor, as physiological and/or environmental, will indirectly affect exercise tolerance, if they influence the perception of how hard the task is[10]. For instance, while muscle fatigue progresses during exercise, central motor command is increased to maintain the required force. Consequently, perception of effort increases and exhaustion (i.e., disengagement) approaches. Thus, exhaustion can be postponed if individual's potential motivation is higher, once the critical level of perception of effort will be reached later in the same task. Additionally, the Psychobiological model fits the training-induced adaptations (e.g., muscular and cardiorespiratory) related to exercise tolerance improvement to a framework which predicts that these adaptations will influence endurance performance indirectly, by reducing perception of effort[23,24].

As perception of effort is such an essential element in the Psychobiological model, a deeper characterization is necessary, especially due to its somewhat controversial and still debated mechanisms presented in the literature. Briefly, the mechanisms underpinning the perception of effort are thought to be either based on afferent or efferent signals[25-27]. Strong evidence proposes that perception of effort is independent of peripheral afferent feedback signals[26], and that perception of effort and other sensations (e.g., pain, temperature, etc) present two separate neurological mechanisms[28]. In addition, there is direct neurophysiological evidence that movement-related cortical potential amplitude during movement execution correlates with perception of effort[29]. Despite all this, the presence of feedback influences in the generation of perception of effort is still not ruled out[30]. For the purposes of this work, however, and under the framework of the Psychobiological model, the mechanism assumed will be the 'corollary discharge' theory, which postulates that perception of effort is the conscious awareness of the central motor command sent to the active muscles[26,29,31]. Changes in perception of effort, though, can also result from altered central processing of the corollary discharges[32]. Therefore, feedback from the muscles and other tissues may influence but not directly generate the perception of effort. For example, rating of perception of effort should be very high in the minutes following severe exercise due to the delayed washout of metabolites, but this is not the case.

The Psychobiological model is supported by the observation that people exercise until very high levels of perception of effort, eventually disengaging in similar end-values, with no apparent physiological failure[15,33-35]. In order to check experimental evidence for this observation, individuals performed a high-intensity endurance exercise test to exhaustion, immediately performing a new task (8 s all out sprint) after exhaustion, with no previous knowledge about it[15]. The average power output produced during the all-out sprint was ≈ 3 times greater than the one required during the high-intensity endurance test, showing that central and/or peripheral muscular fatigue[36] and/or physiological catastrophe failure[37] cannot explain the individuals' endurance test disengagement. In addition, the perception of effort was extremely high at the endurance test exhaustion (19.6 a.u.), indicating its role as endurance-exercise limiter[15].

Additional corroboration for the Psychobiological model comes from two previous studies. In the first study[14], after performing an eccentric-induced fatiguing protocol, which does not affect metabolic stress and sensitivity of muscle afferents, individuals exercised until exhaustion during a high-intensity endurance test. Compared to the control situation, individuals with eccentric-induced muscle fatigue presented impaired performance and higher cardiorespiratory and perception of effort responses, explained by the increased central motor command necessary to exercise with fatigued muscles. This study dissociated metabolic stress from the impairment in performance induced by locomotor muscle fatigue, and showed that the net result of muscle fatigue and the cause of performance reduction was an increased perception of effort[14]. The second study tested the effects of mental fatigue on endurance exercise performance[16]. Mentally fatigued individuals presented a reduction in exercise performance compared to the control condition, associated with higher perception of effort values. Interestingly, heart rate and blood lactate were significantly higher during the control exhaustive condition, suggesting that exercise disengagement occurred at submaximal physiological states in the mentally fatigued subjects, despite similar end-values of perception of effort[16]. Therefore, supporting the Psychobiological model, there are experimental evidences that endurance-exercise performance is ultimately regulated by perception of effort, and not due to physiological failures (e.g., cardiorespiratory or energetic)[14,16,38,39].

Exercise (in)tolerance and regulation during open- and closed-loop exercises

Open-loop tasks are defined by the absence of a known endpoint[40], and the most common types of exercise in this category are constant power/force output (also called time to exhaustion) and incremental tests. During both types of exercise, individuals should maintain the required power/force for as long as possible. On the other hand, closed-loop tasks are defined by the presence of a known endpoint, which is normally expressed in distance or duration[40]. In this category, the most common type of exercise is the time-trial test, in which individuals are able to choose their power output throughout the task (self-paced). During this type of exercise, individuals should complete the task in the fastest time possible.

In the light of the Psychobiological model this division is important as open- and closed-loop exercises require decisions of different complexity to explain its regulation and (in)tolerance. The open-loop exercises require a simple behavioral decision by the individuals (i.e., continue or stop) and can be explained by the two main psychological components of the Psychobiological model: a) perception of effort; b) potential motivation. On the other hand, closed-loop exercises demand a rather more complex decision (i.e., anticipation and moment-by-moment decisions about the pace), requiring three additional psychological constructs: c) knowledge of the distance/time of the task; d) knowledge of the distance/time elapsed; e) previous experience of the relationship between workload and exercise duration on perception of effort[10]. Hence, we will present both separately to better account for their particularities.

Open-loop exercises

During both time to exhaustion and incremental tasks, perception of effort increases over time[33,35,41,42] and high values determine exercise disengagement (i.e., exhaustion). It occurs when individuals are not willing to invest the required effort or believe the task is impossible[11,14]. In addition, based on perception of effort, the Psychobiological model is able to explain why individuals stop exercising with different physiological bodily states, in different environmental conditions, and under several external manipulations. For instance, cycling with pre-fatigued locomotor muscles results in earlier exercise termination, and this can be explained by the reduction in the muscular apparatus responsiveness and the consequent increase in central motor command and perception of effort to maintain the same absolute power output compared to the non-fatigued state[14]. The same mechanism of increased central motor command and perception of effort is thought to reduce exercise tolerance in moderate levels of hypoxia, where muscle fatigue occurs more rapidly[43] and respiratory muscles effort is higher at a given time point[44]. Additionally, individuals disengage earlier from a time to exhaustion exercise when mentally fatigued[16]. This is explained by the higher levels of perception of effort once mentally fatigued, as cardiorespiratory and muscular/energetic parameters did not differ between conditions[16]. On the other hand, the Psychobiological model also accounts for the explanation of increased endurance exercise tolerance under a variety of manipulations, for example, music[45], verbal encouragement[46] and competition[47]. In these cases, individuals' willingness to exert effort (i.e., potential motivation) is increased and the raise in perception of effort can be delayed[48,49], resulting in a longer exercise tolerance[11].

Closed-loop exercises

According to the Psychobiological model, closed-loop exercises are self-regulated tasks, in which individuals determine their own pace throughout the exercise primarily based on two cognitive/motivational factors described on the "Open-loop exercises" section (perception of effort and potential motivation) and three additional ones: III) knowledge of the distance to cover; IV) knowledge of the distance covered/remaining; V) previous experience/memory of perception of effort during exercises of varying intensity and duration (10). In closed-loop exercises, individuals have to choose which pace they are going to employ throughout the task in a moment-to-moment basis. Marcora[10,11] advocates that, as finishing the task is paramount, individuals normally choose a slightly conservative pace at the beginning and middle parts of the task because conscious prediction of perception of effort near the end of the task is not reliable. Only near the end, when individuals know that the task is finishing and changing the pace will not compromise their performance, they increase their speed/power. This speed/power increment at the end of the task is known as end-spurt. In actual sports events, when the aim is normally to win rather than set the best time possible, changes in the pacing strategy can be modified by factors extrinsically to the five cognitive/motivational aspects here discussed (e.g., tactical considerations, knowledge of competitors position and state, etc).

All the experimental manipulations mentioned in the "Open-loop exercises" section (e.g., pre-fatigued muscles, hypoxia, music, competition, mental fatigue, etc) have the potential to alter the pace at which closed-loop exercises are performed. While during open-loop exercises these manipulations would either reduce or augment exercise tolerance, during closed-loop exercises individuals are able to compensate by voluntarily changing the speed/power at which they are performing the task[13]. For instance, if the result of certain manipulation is an increased perception of effort, individuals might compensate by voluntarily reducing the pace, which results in perception of effort decrements. This behavioral strategy (i.e., changing the pace) maintains perception of effort within acceptable limits to ensure that it will be maximal only at the end of the task, guaranteeing successful completion of the task[13]. Hence, performance during closed-loop tasks can be altered by higher or lower potential motivation and perception of effort through changes on conscious self-regulation pacing strategy[10].

Future directions

The Psychobiological model of endurance exercise performance is a relatively new model in the literature to explain endurance exercise intensity regulation and (in)tolerance. Here, we presented experimental evidence and summarized the key points of the model, which is based on two psychological constructs: perception of effort and potential motivation. This model differs from its predecessor's as it confers crucial importance and direct effect of psychological factors on exercise performance. In fact, according to this model, physiological influences on endurance exercise intensity regulation and (in)tolerance are only indirect, as it will affect performance only if affects either psychological constructs in which the model are based. This new framework might give new perspectives to the future of the research on endurance exercise performance, by guiding new interpretations, scientific problems, and applications.

This paradigm provides exercise scientists with a new framework to work on, emphasizing the importance of exercise psychology and neuroscience related to sports performance. For instance, a more complete understanding of the human's cognitive control and motivational aspects during exercise is required, as it might play direct influence on the ability to resist to high levels of perception of effort. For example, the anterior cingulated cortex, known to process sensory, motor and emotional cognitive information is directly influenced by physical activity, increasing its size and efficiency[50]. This could be one of the mechanisms by which training-induced improvements in performance occur, but determination of causal relationship is warranted. Additionally, research on drugs and brain mechanisms able to influence perception of effort, cognition and mood such as caffeine and modafinil can bring significant contributions to physical activity levels for cancer patients, chronic obstructive pulmonary disease patients, etc. Transcranial direct current stimulation and transcranial magnetic stimulation may also be useful tools to stimulate brain regions involved in the processes of perception of effort and motivation, influencing exercise tolerance.

One of the most exciting and promising avenue to the next years is the investigation of psychological interventions aiming to modulate potential motivation during endurance exercises, such as associative/dissociative strategies[48], psychological skills training[51], increased arousal[52], and subliminal stimulation[53]. The next Olympic Games in Brazil may be a good opportunity to testify such results.

Resumo

Modelo psicobiológico: uma nova explicação para o controle da intensidade e (in)tolerância durante exercícios de resistência cardiorrespiratória.

Os mecanismos que explicam fadiga e exaustão, controle da intensidade e (in)tolerância ao exercício de resistência cardiorrespiratória têm sido estudados há mais de um século. Apesar de diversas teorias científicas atualmente disponíveis, nos últimos cinco anos um novo modelo chamado de Psicobiológico tem sido proposto. Este modelo dá maior importância aos fatores perceptuais e motivacionais em relação aos seus antecessores, bem como a respectiva influência destes fatores no processo consciente de tomada de decisão e controle comportamental. Nesta revisão, nós apresentamos evidências experimentais e sintetizamos os pontos chaves do modelo Psicobiológico que explicam o controle da intensidade e (in)tolerância ao exercício de resistência cardiorrespiratória. Adicionalmente, nós discutimos como o modelo explica as adaptações ao treinamento relacionadas à melhora no desempenho, as manipulações experimentais e suas predições. Ao final, propomos futuras direções para esta área investigativa. O modelo Psicobiológico pode proporcionar uma nova perspectiva aos resultados anteriormente publicados na literatura, ajudando os cientistas a entenderem melhor seus problemas de pesquisa, assim como analisar e interpretar novas evidências mais precisamente.

Palavras-chave: Desempenho no exercício; Fadiga; Esforço percebido.

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