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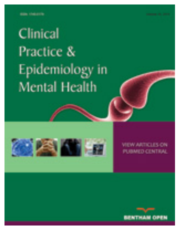

REVIEW ARTICLE

Prior Acute Mental Exertion in Exercise and Sport

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Abstract:

Introduction:

Mental exertion is a psychophysiological state caused by sustained and prolonged cognitive activity. The understanding of the possible effects of acute mental exertion on physical performance, and their physiological and psychological responses are of great importance for the performance of different occupations, such as military, construction workers, athletes (professional or recreational) or simply practicing regular exercise, since these occupations often combine physical and mental tasks while performing their activities. However, the effects of implementation of a cognitive task on responses to aerobic exercise and sports are poorly understood. Our narrative review aims to provide information on the current research related to the effects of prior acute mental fatigue on physical performance and their physiological and psychological responses associated with exercise and sports.

Methods:

The literature search was conducted using the databases PubMed, ISI Web of Knowledge and PsycInfo using the following terms and their combinations: “mental exertion”, “mental fatigue”, “mental fatigue and performance”, “mental exertion and sports” “mental exertion and exercise”.

Results:

We concluded that prior acute mental exertion affects effectively the physiological and psychophysiological responses during the cognitive task, and performance in exercise.

Conclusion:

Additional studies involving prior acute mental exertion, exercise/sports and physical performance still need to be carried out in order to analyze the physiological, psychophysiological and neurophysiological responses subsequently to acute mental exertion in order to identify cardiovascular factors, psychological, neuropsychological associates.

Keywords: Cognitive exertion, Cardiovascular, Exercise, Neurophysiological, Performance, Psychological, Sport.

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INTRODUCTION

Acute mental exertion is a psychophysiological state caused by a prolonged and sustained cognitive activity, characterized by a feeling of "tiredness" and "lack of energy", and reduced efficiency in cognitive performance, called cognitive fatigability [1 - 3]. Understanding the possible effects of mental effort on the motor performance and its associated neuro-psyco-physiological responses is of great importance for the development of different occupations such as the military, construction workers, athletes (professional or recreational) or simply physical exercise practitioners regular. These individuals often combine to perform mental and physical tasks [4].

Isolated execution of a mental effort derived from a cognitive task triggers some physiological responses associated with the activity of the hypothalamic-pituitary-adrenal axis (HPA) and sympathetic-adrenal (SA) [5 - 8]. For example, mental efforts can activate the HPA axis and SA and increase the release of hormones such as catecholamines (epinephrine and norepinephrine) and cortisol [5, 6, 8]. When mental efforts are combined with physical exercise, hormonal and cardiopulmonary responses during physical exertion are exacerbated [9 - 13]. Consequently, due to the control exercised by the HPA axis and SA on the cardiopulmonary system, it is suggested that the combination of mental stress and exercise can trigger major cardiopulmonary responses in these conditions [14, 15]. For example, higher elevations in the response of ventilation (VE), heart rate (HR), respiratory rate (RR) were observed when a mental exertion derived from a cognitive task was performed over a continuous exercise at 60% of maximal oxygen (VO_{2MAX}) [4].

In fact, studies have found that the interaction between mental exertion and exercise can elevate cardiopulmonary responses while performing the physical effort [16 - 18]. The exception was a result reported by a recent study, which has not observed interaction effects between mental effort and physical exercise on the cardiopulmonary responses of physical exertion [19]. In this study, the execution of a previous mental task did not alter the kinetics of VO_2, peak VO_2 and economy of movement during exercise constant overhead to 80% of mechanical power peak obtained in preliminary incremental exercise. The interesting point was that the implementation of mental effort produced a reduction in physical performance and increase in rate perceived exertion (RPE) [19]. The authors proposed that the execution of a prior mental effort may have altered activation of cortical centers involved in motor control, raising the RPE-exercise and reduced exercise tolerance. These results brought perspective contrary to the traditional model of exercise physiology, it is indicated that changes in the physical performance after performing mental tasks could dissociate the physiological changes such as, for example, cardiopulmonary responses [19].

As far as we know, few studies were designed to investigate the effects of prior acute mental exertion on cardiopulmonary responses and physical performance [19 - 21]. For example, Marcora, Staiano and Manning [19] found that the previous performance of a mental exertion reduced exercise tolerance in a constant power test, without changing the cardiopulmonary responses.

The possible implications that a prior mental effort may have on exercise tolerance during a subsequent exercise are important for the understanding of engine performance phenomenon and regulation of stress in different models of aerobic exercise [19, 20]. For example, athletes and regular exercise practitioners are often subject to a combination of stressors, cognitive and physical nature, during training and competitions. However, it is unclear whether a prior mental exertion caused by a cognitive task affects negatively physical performance and psychophysiological responses associated with the subsequent exercise. The integration of physiological and psychological factors during the exercise is in line with current trends in the field of exercise science and sports. In addition, understanding the possible implications that the mental exertion derived from a cognitive task has on exercise tolerance may be important, not just for the physical exercise performance, but also to occupational performance. For example, professionals who perform functions within the military, construction and mechanics, among others, are often subject to a combination of stressors, mental and physical, while conducting their activities [4].

Therefore, our narrative review aims to provide information on the current research related to the effects of prior acute mental fatigue on physical performance and their physiological and psychological responses associated with exercise and sports. We will review the brain, cardiovascular, neuropsychological and performance responses of acute mental exertion in sport and exercise.

METHODS

The literature search was conducted using the databases PubMed, ISI Web of Knowledge and PsycInfo using the following terms and their combinations: "mental exertion", "mental fatigue", "mental fatigue and performance", "mental exertion and sport" "mental exertion and exercise". All articles were published between 1989 and 2014 in English language. Additional references were identified through hand search of the possessed articles. From own references found in the electronic databases, a manual was also performed. The following data were extracted from the articles: sample, protocol mental exertion, psychological measures, exercise measures (performance) and exercise model.

RESULTS

Mental Exertion

The mental exertion derived from a cognitive task is characterized by engaging in a cognitive activity which, when prolonged and/or intense, can induce during or after their execution at a psychophysiological state of mental exhaustion, characterized by subjective feelings of "lack of energy "and" fatigue " [3, 22], a feeling of discomfort and decreased motivation, defined the cognitive fatigability [1, 2]. Also, the decline in executive functions, executive attention, selective attention, sustained attention, alternating attention, inhibitory response, planning and processing of new information are common features to the mental effort derived from a cognitive task [1, 2].

Tanaka *et al*. [23] evaluated cognitive function from performing 30-minute cognitive task in selective attention and simple attention on a sample of 12 healthy individuals. In this study, the subjects developed in a randomized way, induce cognitive task sessions of mental fatigue or rest (control). The results demonstrated that performance of the cognitive task increased significantly simple selective attention of reaction time compared to the control condition. Also, significant difference occurred on percentage error of the cognitive task, as presenting experimental condition increases over time compared to the control condition. This study evidenced that mental task may entail a deterioration of cognitive function, decreased with selective attention may be a specific characteristic of mental exertion derived from a cognitive task, and this high mental effort can lead to an increased inhibitory response. One possible explanation is that induced mental task by means of cognitive activity can cause increased activity of cortical regions, for example, the anterior cingulate cortex and the dorsolateral prefrontal cortex [1, 2, 23].

Moreover, the negative effects of mental exertion derived from a cognitive task are known and have an influence on decision making, attention, motivation, cognitive control and voluntary decision to stay or not in a running or subsequent task [3, 24, 25]. It is noteworthy that mental exertion is often self-reported by athletes during physical training and working professionals on extended shifts [5, 26].

It is speculated that engaging in a cognitive task induces accumulation of adenosine in the anterior cingulate cortex, generating a greater sense of effort in subsequent tasks. This speculation is based on previous studies in humans showed that the anterior and posterior cingulate cortex is strongly activated during cognitive tasks of sustained attention and memory [27, 28], which are associated with the perceived exertion [29, 30]. Moreover, experimental evidence in animals and *in vitro* observed that the neural activation increases the extracellular concentration of adenosine [31] and that increased brain adenosine associated decrease in the engine performance [32].

Interestingly, studies suggest that the cognitive task that induces mental fatigue may have systemic effects, such as changes in the concentrations of amino acids in the blood [33, 34]. Furthermore, the sustained mental effort has been associated with increased brain adenosine and reduced brain glycogen [35, 36]. These and other unknown mental effort systemic changes can theoretically cause the onset of symptoms and peripheral signs of fatigue [37].

The relationship between mental exertion and decreased cerebral energy metabolism has been studied using spectroscopy 31P-magnetic resonance. Kato *et al.* [38] evaluated the occipital cortex during cognitive task in ten volunteers by means of spectroscopy 31P-magnetic resonance and found that there is a reduction in creatine phosphate measured during mental exertion was significantly associated with decreased cognitive performance ($r = -0.86$, $p < 0.005$) and that the reduction of pH after the cognitive task was associated with marked reduction of cognitive performance ($r = 0.78$, $p < 0.01$), event called cognitive decrement. According to the authors, these findings suggest that brain energy metabolism is related to intrinsic factors of mental effort [38].

Moreover, repeated and prolonged cognitive task causes mental dysfunction facilitation system (consisting of the thalamic frontal lobe that interconnects the limbic system, basal ganglia, talamus, orbitofrontal cortex, frontal cortex, dorsolateral prefrontal cortex, anterior cingulate cortex, the area pre-motor, the primary motor cortex and supplementary motor area) due to decreased energy metabolism and/or oxidative increase, as well as by over-activation of mental inhibitory system (which consists of the thalamus, cortex sensory secondary motor, insular cortex, posterior cingulate cortex, anterior cingulate cortex, the premotor area, the primary motor cortex and supplementary motor area) causing the decline in cognitive function. Acute mental task activates the facilitation and mental inhibitory systems, as a result, acute mental fatigue is installed. The predominant activation of mental facilitation system maintains or enhances mental performance task, while the major inhibitory system activation decreases mental performance in cognitive task [2]. The unbalance and/or balance the system determines whether the mental performance and cognitive performance in subsequent task (mental or physical) is impaired (inhibitory system) maintained or improved (facilitation system). Therefore, the cognitive task is governed by these two mental systems (facilitation and inhibition mental), which postulated be called dual regulation system [2].

Importantly, Ishii, Tanaka and Watanabe [1, 2] say, the dual regulation system, mental exertion suggests that there may be three types of stress/high mental fatigue, what is caused by insufficient activation of mental facilitation system, which is caused the greater activation of inhibitory mental system and what is caused by the combined effects of these systems. In fact, environmental factors such as unpleasant room temperature and sleep deprivation can affect cognitive function impairment of inhibitory systems and/or mental facilitation, leading therefore acute mental fatigue. However, further studies are needed to explain the characterizing biological mechanisms and triggers of stress/mental fatigue derived from the cognitive task, beyond even the possible acute physiological effects which may result in cognitive function.

Mental Effort and Brain Responses

Recent studies have sought to investigate the effects of mental exertion on brain responses in diverse populations [2, 39, 40]. And has postulated that the neural mechanism of mental effort sensations caused by the cognitive task is related to mental inhibitory system [3]. It is noteworthy that the inhibitory system consists of a neural network that interconnects the spinal cord, the thalamus, the cortex sensory secondary engine, the insular cortex, anterior cingulate cortex, the posterior cingulate cortex, the premotor area, supplementary motor area and the primary motor cortex [2]. In fact, studies have observed that the neural substrates of mental effort sensations derived from a cognitive task involving the above cortical areas [39, 40].

Otto *et al.* [39] evaluated the neural structures that are activated during mental exertion on 14 healthy subjects, found that the cognitive task is able to activate the cortex anterior and posterior cingulate, the dorsolateral prefrontal cortex, basal ganglia and the cortex insular. Still, these authors found that the activation of the insular cortex is positively related to feelings of fatigue induced cognitive task. In this same line, Cook *et al.* [40] studied 20 individuals of both genders, who underwent cognitive task to determine the association between mental fatigue sensations and level of cerebral blood oxygen functional magnetic resonance imaging. The results found by these authors were significant positive associations between feelings of mental fatigue and brain activation during a cognitive task, with the brain regions of the anterior and posterior cingulate cortex, the inferior frontal cortex and superior temporal and cerebellum. Still, significant negative correlation was found between the feeling of mental fatigue and the activation of the left posterior parietal cortex. The authors suggest that the mental fatigue feelings are related to neural responses in a cognitive task, perhaps represented by adjustments to maintain cognitive performance.

Ishii, Tanaka Watanabe [1] investigated the neural mechanisms underlying the self-assessment of mental fatigue levels due to a cognitive task in 14 healthy subjects. Once the neural mechanisms of self-evaluation of mental fatigue level can involve multiple regions of the brain, the authors used the high temporal resolution magnetoencephalography to assess neural activity resulting from the cognitive task. Thus, the authors showed that the region of the posterior cingulate cortex was the most active region during the cognitive task in seven of the 14 individuals and that the extent of the delta band power decreases in that region during the execution of cognitive task. Still, there was a decrease of delta band power in the dorsolateral prefrontal cortex and that this reduction was positively associated with greater activation of the cingulate cortex posterior and greater feelings of mental fatigue derived from the cognitive task. Thus, the results suggest that the posterior cingulate cortex and dorsolateral prefrontal cortex are involved in and related to the self-evaluation of feeling of mental fatigue, and are activated during performance of a cognitive task [1].

The involvement of the insular cortex and the posterior cingulate cortex neural mechanism of mental fatigue feelings has been suggested in a study that focused on the neural substrates activated during the execution of cognitive task. In this study, cortical activation *via* magnetoencephalography was observed in the posterior cingulate cortex and cingulate cortex when individuals performed a cognitive overload. From these results the authors suggest that the insular cortex is involved in controlling the physiological state of the body and the posterior cingulate cortex is involved in self-control. Therefore, it is plausible that these two brain regions are related to the sensations of fatigue and mental inhibitory system [41].

Other studies have sought to investigate the effects of cognitive task in cortical electrical activity. Brownsberger *et al*. [21], by applying a cognitive task for 90 minutes in healthy subjects, found that mental overload can increase cortical activity beta wave, which is associated with greater attention to the information process and cognitive engaging in mental activities sustained. Yet, while performing a cognitive task, the increased cortical arousal has been located in the prefrontal region of the cortex, where factors such as attention and decision making are known to influence the activity [21]. On the other hand, the power of the alpha band in the frontal cortex is smaller after performing a cognitive task, and this reduction is associated positively with decreased cognitive performance. Considering that mental tasks that require memory, sustained attention and vigilance, requiring high cognitive levels that are probably responsible for the increased activity of beta wave (13-30 Hz) in the frontal brain. Additionally, high beta wave activity is also observed in cognitive processes, attention and sustained emotions and may be responsible for originating feelings of mental fatigue and increased activation of mental inhibitory system [3].

These results help to explain considerable in relation to the effects of cognitive task in motor performance [1, 2, 42], however, further studies are necessary in relation to the activated brain mechanisms during the cognitive task and that may affect the motor performance. As discussed above, the insular cortex and posterior cingulate cortex are candidates cortical regions that are related to mental inhibitory system. However, these cortical regions can inhibit mental performance and/or power from other brain regions, *e.g*., the frontal area. In fact, the dorsolateral prefrontal cortex has been postulated as a cortical region that determines the cognitive and motor performance, gateway to the inhibitory systems and facilitation [2].

Mental Exertion and Cardiovascular Responses

The execution a mental effort derived from a cognitive task triggers cardiovascular responses associated with the activity of the SA and HPA [8, 10 - 13], since the execution of cognitive tasks may enable the shafts SA and HPA and increase the secretion of hormones such as catecholamines (epinephrine and norepinephrine) from the axis SA, and cortisol, from HPA axis [8], hormones responsible for cardiovascular responses due to the stress-factor. In addition to the modulation of SA and HPA axis, when an individual goes through an acute mental effort, a complex chain reaction occurs, resulting in responses that occur within the SA and HPA axis, and the ways of the sympathetic nervous system (SNS) and parasympathetic (SNP) of the body [13]. Therefore, it has been suggested that increases in HR and blood pressure responses during cognitive task are due to decreased vagal tone assigned to the SNP, as a result of rhythmic changes in heart rate mediated by a spinal mechanism of the brain stem through the vagus nerve [43] and/or increased sympathetic afferent neuromuscular activation [44].

Smeets [43] studied the relationship of physiological responses to mental exertion arising from a cognitive task in the cardiovascular response, specifically in cardiac vagal tone to it made a sample of individuals of both sexes (n = 68; 34 men and 34 women) to a cognitive task (arithmetic tasks) with continuous monitoring of the autonomic response (CR, salivary alpha-amylase), HPA (salivary cortisol) and the psychological stress level. The results showed that the cardiac vagal tone at rest is associated with increases induced by cognitive task in cortisol concentrations, and that the decrease in vagal tone is associated with increases induced by mental task in the subjective perception of stress, with HR and the concentration of salivary alpha-amylase. These results suggest the influence of SNS on the regulation of HR may, in part, determines the HPA axis responses to mental stress due to cognitive task. Smith, Mitchell and Garry [44] studied the increase in sympathetic activation afferent said compressor reflection contributes significantly to regulating the cardiovascular system during stressing mechanism cognitive task, since the physiological responses induced by mental effort comprise arm afferent reflex sympathetic, which are generated by the activation of chemically sensitive receptors (metaboreflex). Activation of these receptors and their associated afferent fibers set reflexively sympathetic and parasympathetic nerve activity during mental effort [44].

Some studies have shown a possible effect of mental effort on HR responses. Pageaux, *et al.* [20] investigated the effects of mental effort lasting 30 minutes on the HR in 12 healthy adults, found that the average HR was higher and significantly different during mental exertion compared to the control condition. In another study, Pageaux, Marcora, Lepers [37] submitted ten male adults and physically active at a cognitive task 90 minutes continuously monitoring the HR during their execution. In this study, the authors demonstrated a decrease in HR over the day of mental task in both conditions (experimental *vs.* control), but the average values were significantly higher in the experimental condition compared to the control condition (73 ± 1 bpm *vs.* 69 ± 1 bpm to experimental and control, respectively). In this sense, most HR observed during the cognitive task compared to the control condition, it confirms the natural demand of mental effort, in fact, the increase in HR and other cardiovascular disorders are associated with stress during cognitive activities. Pageaux, Marcora, Lepers [37] reported that the natural requirement of the mental task was applied, it is not surprising that 90 minutes from the cognitive task induced a significant increase in subjective feelings of mental effort.

In the study by Pageaux, Marcora, Lepers [37] the HR response was checked during execution of the cognitive task. In another study, by Marcora, Staiano, Manning [19], using a cognitive task 90-minute protocol was used which showed that performing a mental task (experimental) is able to increase significantly the mean values of HR compared to the control condition (65 ± 8 bpm *vs.* 62 ± 8 bpm for experimental and control, respectively). Corroborating the previously mentioned studies, Barbosa *et al.* [45] investigated the cardiopulmonary responses of two versions of a cognitive task (computerized and verbal), including the HR. In this study, the sample consisted of 20 participants who performed the computerized version of the Stroop and verbal test. First, the results of this study suggest that both versions of the cognitive task are able to significantly raise the final values of the HR when compared to baseline measurements. Still significant differences occurred in systolic blood pressure compared the measures immediately after the tests with the baseline. Second, there have been, however, significant differences in blood pressure measurements, HR and sinus arrhythmia between versions of the Stroop test. One possible explanation for the changes in physiological measurements can be attributed, at least in part, to sympathetic neurohumoral activation due to the informational processing demand [45].

Still, it is possible that the decrease in vagal activity, expressed in this study by the measures of respiratory sinus arrhythmia, contributed to the increase seen in HR while performing cognitive tasks. Indeed, activities that require high levels of mental effort and selective and sustained attention processing can result in reduction of parasympathetic tone and homeostatic changes [46]. And, these results support the evidence that complex interactions between the sympathetic-parasympathetic systems occur when participants perform tests that demand states of attention and acute psychological stress [45].

Moreover, Brownsberger *et al.* [21] investigated the cognitive task execution protocol for a period of 90 minutes in 12 participants of both genders (eight men and four women) in HR responses showed no significant differences in mean values of the variable in the conditions (80.8 ± 8.1 *vs.* 80.3 ± 7.5 bpm; 40.9% and 41.2% of maximal HR, experimental and control, respectively). In this sense, and considering the aforementioned studies, the explanation for the presence or absence of cardiovascular reactivity induced mental task can be assigned to different mechanisms such as vascular and cardiac factors. One mechanism that has been suggested to account for differences in cardiovascular responses during cognitive task is the increased sensitivity to alpha and beta adrenergic receptors. Other proposed mechanisms that may be responsible for higher cardiac output is the increased sensitivity and/or density of myocardial adrenergic receptors [10].

Thus, the authors demonstrated that the increase in HR and other cardiovascular parameters observed during and after implementation of a mental task, compared to condition without mental task, realize the most natural demand of cardiac activity during mental effort [44, 45]. In addition, most natural demand of the cognitive task is confirmed by the greater perception of mental exertion reported by the subjects [19, 20, 37].

Mental Exertion and Psychological and Neuropsychological Responses

Ishii, Tanaka, Watanabe [1, 2] characterized the physiological responses derived from a mental effort as feelings/emotions that are often accompanied by peculiar feelings of discomfort, decreased motivation and a “desire to rest”, can also be characterized by a feeling of “tiredness” and “lack of energy” [3]. It is noteworthy that these responses play an important role as a biological alarm signal that drives decreased mental and/or physical effort in order to avoid breaking of homeostasis and consequently the disengagement of the activity under conditions in which there is reduction in the ability and/or efficiency in cognitive and/or physical activity. In this sense, studies report that the substrates and physiological responses to mental effort involved brain regions that are involved with mental inhibitory system (insular cortex and posterior cingulate cortex) [1, 2].

Some studies have shown a possible effect of prior mental exertion on psychological responses. Otto, Zijlstra, Goebel [39] investigated brain activity through functional magnetic resonance imaging, and psychological responses (self-reporting of difficulty of the task and mental fatigue) while 14 participants performed a cognitive task during a period of 28 minutes They found that mental exertion caused an increased activity of cortical region of the left anterior insular cortex and that most cortical activity in this region was positively associated with sensations of difficulty of the task and mental fatigue. Cook *et al.* [40] aimed to determine the magnitude of the association between the perception of the intensity of mental fatigue and brain activity measured by functional magnetic resonance imaging in 20 healthy participants. In this study, the perception of mental fatigue is induced from the use of a cognitive task involving attention, working memory and executive function for a period of four minutes and thirty seconds, and psychological responses of force and mental fatigue were evaluated from visual analog scales. The authors found a positive association between increased mental fatigue sensations to the brain activity during the cognitive task, specifically, with increased cortical activity in the frontal, cingulate, temporal and cerebellar. And it evidenced a significant and negative correlation between mental effort sensations and the activity of the posterior left parietal cortex.

Pageaux *et al.* [20] observed the effects of a mental task in the fields of mood in physically trained subjects, and found that the mental task with 30 minutes duration only changed significantly so that sense of vigor among participants, with a reduction over time, without identifying any difference in the field of fatigue. Moreover, the authors observed no significant difference in the performance of a prior mental effort on intrinsic motivation and success motivation. In another study, Pageaux *et al.* [37] observed that the realization of the cognitive task with 90 minutes duration decreased significantly the strength of the field (9.0 ± 0.9 to 6.5 ± 0.9) and increased the area of perceived fatigue by participants undergo this cognitive task protocol. Yet, no effect of mental exertion on intrinsic motivation and success motivation in physical task of subsequent muscular resistance was observed [37].

Brownsberger *et al*. [21] submitted 12 participants to a cognitive task with 90 minutes duration and found that the previous mental efforts increased mental fatigue sensations after their execution, and their values significant difference when compared to the control condition (watch video documentary). Moreover, no acute effects demonstrated prior mental effort on self-reported by survey participant's motivation. In another study, Marcora, Staiano, Manning [19] showed a significant reduction in the vigor (6.2 ± 3.1 to 3.5 ± 2.2), but also significantly increase the field of fatigue after execution of mental effort lasting 90 minutes.

According to the studies cited previously, it is speculated that sustained mental effort and/or heavy derived from a cognitive task may lead to mental sensations defined with increased fatigue sensations and/or decreased vigor and/or decreased cognitive performance. Note that no change of some mental exertion markers may be due to the cognitive task of protocol used, for example, 30 minutes in the study by Pageaux *et al.* [14] and 90 minutes adopted in studies by Pageaux *et al.* [20], Brownsberger *et al.* [21] and Marcora, Staiano, Manning [19].

Mental Exertion and Psychophysiological Responses

The mental exertion derived from a cognitive task is characterized by engaging in a cognitive activity, characterized by subjective feelings of "lack of energy "and" fatigue" [3, 22], the feeling of discomfort and decreased motivation [2] and reduced efficiency in cognitive performance [47]. It is also observed, the decline in executive functions such as the executive attention, selective attention (working memory), sustained attention (vigilance), alternating attention, divided attention, inhibitory response, planning and processing new information are common features to the mental strain derived from a mental task [1, 2].

Among the various components of executive function, selective attention (working memory) is affected by mental fatigue. Tanaka *et al.* [48] evaluated cognitive function from performing 30-minute cognitive task in selective attention and simple attention on a sample of 12 healthy individuals. In this study, subjects performed in a randomized trial, caused cognitive task sessions of mental fatigue (Stroop test, 0-back test and test 2-back) or rest (control) lasting 30 minutes. The results demonstrated that the performance of cognitive tasks increased significantly (522.2 ± 27.1, 512.4 ± 17.6, 548.8 ± 23.9 ms; ± 20.4 344.6, 318.8 ± 10.1, 327.3 ± 9.7 ms; 485.6 ± 25.0, 485.7 ± 17.2, 501.3 ± 17.9 ms [mean ± standard error of the mean]; $p<0.01$ for all) reaction times of simple selective attention compared to the control condition. Still, significant differences (14.0 ± 1.7, 12.9 ± 1.2, 13.4 ± 1.9%, 3.0 ± 0.6, 3.6 ± 0.6, 3.4 ± 0.7%, 5.2 ± 0.6, 4.7 ± 0.9, 4.2 ± 0.5% [Mean ± standard error of the mean]; $p <0.01$ for all) occurred in the percentage of errors of mental tasks with the experimental condition (mental fatigue) presenting increases over time compared to the control condition. This study showed that mental exertion can cause the deterioration of cognitive function, with decreased selective attention can be a particular feature of mental fatigue derived from a cognitive task, and that this state of mental fatigue can lead to an increased inhibitory response. One possible explanation is that cognitive task caused mental fatigue and increased activity of cortical regions, for example, the cortex anterior and posterior cingulate and dorsolateral prefrontal cortex [1, 48].

Moreover, the negative effects of mental exertion derived from a cognitive task are known and have an influence on decision making, attention, motivation, cognitive control and voluntary decision to stay or not in a running or subsequent task [3, 24, 25]. It is noteworthy that mental exertion is often self-reported by athletes during physical training and working professionals on extended shifts [4].

Also, repeated and prolonged mental tasks cause mental dysfunction facilitation system due to decreased energy metabolism and/or increased oxidative, as well as by over-activation of mental inhibitory system causing a decrease of the cognitive function. The acute mental task activates the facilitation and inhibition mental systems, as a result, the acute mental fatigue is installed. The predominant activation of mental facilitation system maintains or enhances mental performance task, while the major inhibitory system activation mental performance decreases in cognitive task [2]. The unbalance and/or balance the system determines whether the mental performance and cognitive performance in subsequent task (mental or physical) will be affected (inhibitory system) maintained or improved (facilitation system). Therefore, the mental effort is regulated by these two mental systems (facilitation and mental inhibition), which postulated be called dual regulation system [1, 2, 41].

Importantly, according to Ishii, Tanaka and Watanabe [2], the dual regulation system of mental effort suggests that there may be three types of acute mental stress: what is caused by insufficient activation of mental facilitation system, which is caused by higher activation of inhibitory mental system and what is caused by the combined effects of these systems. In fact, environmental factors such as unpleasant room temperature and sleep deprivation can affect cognitive function impairment of inhibitory systems and / or mental facilitation, causing therefore the acute mental fatigue. However, further studies are needed to explain the characterizing biological mechanisms and triggers of mental effort derived from the cognitive task beyond even the possible acute physiological effects which may result in cognitive function [2].

Mental Exertion and Motor Performance

Table **1** summarizes the main features and results of studies designed to investigate the effects of prior acute mental exertion on physical performance and psychophysiological responses.

It is surprising that studies have rarely considered the impact of mental effort due to a cognitive task in motor performance [21]. This may be because many researchers assume that the fatigue is a physiological phenomenon caused by energy substrate deficiency within the excited muscle rather than events in the brain or integrative events [49]. In this sense, the studies that are aiming to verify the influence of acute prior mental exertion in subsequent physical tests have been shown to prior mental effort influence negatively the performance in subsequent aerobic physical test [19, 20], in which it is suggested that these negative results may be due to changes in perceived exertion (RPE) when individuals are required by cognitive tasks [50]. However, the mechanisms responsible for this effect on motor performance are not fully understood [21].

It is suggested that the state of mental fatigue, due to cognitive demands, increases the RPE of physical tasks [19, 50], which may explain why individuals perceive greater demands on motor activities, because athletes often attribute worst performance for the mental fatigue and because soldiers are at a higher risk of accidents when they're mentally tired [4]. In addition, recent studies have shown the negative effects of mental exertion induced by prolonged cognitive task (90 minutes) on performance in endurance exercise [19 - 21] and single-joint exercises [37]. Pageaux *et al.* [20] investigated the effects of mental task 30 minutes in performance and RPE in the 5-km time trial race, observed that previous mental efforts increased significantly to RPE over time and impaired aerobic performance from the reduction of the average speed for a 5-km run, when compared to the control condition (mental task without inhibitory response). No significant difference was observed in HR and lactate concentration between conditions. Still, the inhibitory mental task did not affect the pacing strategy chosen by the subjects (negative pacing strategy).

Brownsberger *et al.* [21] found that mental exertion previously installed by performing a cognitive task, a negative performance impact on self-set exercises by different perceptions of effort (RPE-11 and RPE-15), due to lower production of power output compared to the condition control. Still, participants reported greater feelings of mental fatigue and exhibited greater activation of beta wave of frontal brain. The same authors state that future studies can evaluate procedures to alleviate the feeling of mental fatigue and the consequent effect on the motor performance, and considering experimental design, including placebo/sham conditions to eliminate the possibility that expectations are a factor of confounding the observations of the studies [21].

Marcora, Staiano, Manning [19] measured the motivation related to exercise, RPE and performance and physiological responses associated in 16 healthy subjects in aerobic endurance exercise after performing a mental task 90 minutes. They observed that previous mental effort was able to reduce significantly the time to exhaustion compared to the control condition. It is noteworthy that, in this study, any effect of mental exertion on the metabolic, respiratory and cardiovascular responses was not observed during exercise cycling high intensity, however, in the end of the exercise, the average values of HR and lactate concentration were significantly higher in the control condition (video documentary) compared to experimental condition (mental task). Yet, the performance-related motivation was not affected by prior mental effort. In this study, only one factor explained the premature disengagement of the exercise, which is the biggest RPE reported by individuals tired mentally.

Pageaux *et al.* [37] in order to test the hypothesis that prior prolonged mental exertion reduces the maximum muscle activation (neuromuscular function) and increases the length of the central fatigue induced by subsequent resistance exercise, referred ten participants at two different conditions: with sustained mental effort that generates exhaustion mental and a control condition (video documentary). Both cognitive tasks were 90 minutes long and were followed by submaximal exercise isometric knee extension muscles to exhaustion and assess the neuromuscular function. In this study, the authors observed that the time to exhaustion was 13 ± 4% lower in the experimental condition (mental task) compared to the control condition (video documentary), also the individual exhaust times were lower in the experimental condition compared to the control condition in eight ten participants.

It is worth mentioning that the RPE-site increased significantly during physical task of resistance, with higher average values being presented in the experimental condition compared to the control condition. However, when assessing the neuromuscular function (electrical stimulation, mechanical reminders and electromyography - EMG) and the extent of central fatigue, significant differences were observed between the conditions [37]. This study showed that the negative effects of prolonged mental exertion on the motor performance to be mediated largely RPE experienced by individuals mentally tired during physical task. And it suggests that the different effects of prolonged mental task and resistance exercise in maximum muscle activation are associated with different neurochemical changes in the brain that take place at different areas of the central nervous system (CNS) [37]. In this study, the authors suggested a possible interaction between cognitive demand due to the mental task and changes in CNS ability to recruit maximally active muscles. However, no action validates maximum muscle activation was included in the study. In this regard, more research is needed to get a better view of the possible effects of prolonged and prior cognitive task in maximum muscle activation [37]. Depending understanding Ishii, Tanaka Watanabe [1], possibly the mental inhibitory system not only suppressed the performance on mental task, but also the performance in physical task, since these results support the idea that mental inhibitory system has shares common neural substrates with the physical inhibitory system having insular cortex and the posterior cingulate cortex as strong candidates.

Investigating the effects of a mental task in the production of muscle strength, another study [51] aimed to investigate the effects of a mental task in the strength of maximum intermittent voluntary muscle contraction over time in 38 students sedentary graduation, of both sexes. The cognitive task was defined as performing 22 minutes of a mental task of memory and selective surveillance and sustained (Stroop test). The results showed a linear decrease in power output (relative to baseline) over time, with significant differences between the conditions in minutes 16, 19 and 22 performing the physical task with the experimental condition exhibited lower values average compared to the control condition. Still, this study showed higher mean values and growth RPE throughout the realization of the physical task time in the experimental condition compared to the control condition. However, it observed no significant difference in EMG between the conditions, and no association was observed between the RPE and the production of muscle strength [51].

Similar to the study by Bray *et al.* [51], Bray *et al.* [52] investigated the effects of a cognitive task in maintaining 50% of maximum voluntary muscle contraction grip and EMG activity of the wrist flexors, in 49 university students of both genders, they found that the implementation of inhibitory mental task was able to reduce the performance of the maximum muscle contraction grip, regardless of the finding of subjective feelings of stress / mental fatigue. However, a significant difference was observed between conditions in frustration rate cognitive performance with the experimental condition frustration showing greater rate than the control condition. Moreover, the results also revealed that in the inhibitory mental task higher values were observed in the amplitude of EMG of the muscles of the wrist flexors than in the control condition. According to this study, it is suggested that mental task contributes to muscle fatigue by central inhibitory descending neural activation motor unit that are required to sustain submaximal muscle contractions [52]. In this study, the authors suggested a possible interaction between cognitive demand due to the mental task and changes in CNS's ability to recruit maximally active muscles. However, no action validates maximum muscle activation was included in the study. In this regard, more research is needed to get a better view of the possible effects of prolonged mental task in maximum muscle activation [42, 52].

Table 1. Main results of the prior acute mental exertion on physical performance and psychophysiological responses.

Author/ Year	Sample	Protocol mental exertion (Intervention)	Psychological measures	Exercise measures	Exercise model	Mains results (psychophysiological)	Mains results (performance)
Bray *et al*. (2008)	49 subjects (21,25±1,70 years), 35 women.	3 min 40 seconds – teste Stroop or control	Fatigue, effort, pleasantness of the task, frustration, mood	Isometric handrip task EMG hand and wrist flexors Force recording	Isometric handrip task – 50% MVC	↔ Mental effort ↔ Fatigue ↔ Pleasantness of the task ↔ Mood ↑ Frustation ↔ RPE	↔ Handgrip endurance performance ↔ Force ↔ EMG
Marcora, Staiano, Manning (2009)	16 subjects (26±3 years), 6 women	90 minutes– AX-CPT test or control	BRUMS Motivation	Physiological and perceptual	Rectangular workload 80% of peak power output	↑ HR ↓ [Gli] ↑ Fatigue ↓ Vigor ↔ Motivation ↑ RPE	↔ RPM ↓ TE ↔ HR ↔ VS ↔ CA ↔ MAP ↔ VO_2 ↔VE ↔ [Lac]
Bray *et al.* (2012)	38 subjects (21,47±3,16 years), 23 women	22 minutes – Stroop test or control	Visual analogue scale RPE	Isometric handgrip force generation EMG hand flexors	Intermittent maximum hand squeezes	↑ Mental effort ↑ RPE ↔ EMG ↔ Fatigue	↓ MVC ↔ EMG
Brownsberger *et al.* (2013)	12 subjects (24±5 years), 4 women	90 minutes continuous cognitive test	Visual analogue scale	Mean power output	Self-paced exercise RPE (11 e 15)	↑ Fatigue ↔ HR ↔ [Gli] ↔ Motivation ↔ Mood	↓ Power output
Pageaux, Marcora, Lepers (2013)	10 subjects (22±2 years)	90 minutes - AX-CPT test or control	BRUMS Motivation	Time to exhaustion MVC	Submaximal isometric knee extensor exercise	↑ HR ↑ Fatigue ↓ Vigor ↔ Motivation ↑ RPE	↓ TE ↔ MVC ↔ Amplitude e duração da onda M para o VL e RF.
Pageaux *et al.* (2014)	12 subjects (21±2 years), 4 females	30 minutes –Stroop or control	BRUMS Motivation	HR [Lac] [Gli] Performance	Time trial 5-km	↑ HR ↔ [Gli] ↔ Fatigue ↔ Motivation ↓ Vigor ↑ RPE	↓ Performance 5-km ↓ Running speed ↔ Pacing strategy ↔ [Lac]

[Gli]: glucose concentration; [Lac]: lactate concentration; MVC: maximal voluntary contraction; CA: cardiac output; EMG: electromyography; HR: heart rate; MAP: mean arterial pressure; RPE: rate perception exertion; VE: ventilation; VO_2: volume oxygen; RF: rectus femoris; RPM: rotation per minute; TE: time to exhaustion; VL: vastus lateralis;

DISCUSSION

These results support the Psychobiological Model of Endurance Performance [53] which states that exhaustion is not caused by muscle fatigue, which is the neuromuscular system fails to produce the strength/power required for the physical task at a maximum voluntary effort, but a conscious decision for disengage physical task, for instance, a greater increase in RPE, psychophysiological response as it plays an important role in the limitations/tolerances of aerobic performance [19, 50]. It is noteworthy that these recent studies using more prolonged cognitive effort (90 minutes) induced a significant mental fatigue, defined by increases in the subjective sense of mental fatigue [19, 42, 50] and/or decrease the vigor [19, 20, 50] and/or reduction in cognitive performance [19, 20, 37]. In contrast, Pageaux *et al.* [20] found that mental exertion induced changes in cognitive performance (increase in reaction time and/or decrease in accuracy), with no significant change in subjective feelings of fatigue. A previous study suggests that greater perception of effort experienced by individuals who carried out the cognitive task during exercise can be due to changes in central processing of sensory signals [19]. Future studies are needed to understand the underlying neurophysiological mechanisms of the effects of mental task in perceived exertion during resistance exercise [37].

With respect to the pacing strategy, Pageaux *et al.* [20] concluded that the only significant effect of prior inhibiting mental task was to reduce the running speed chosen by the subjects during the time trial 5-km, with no difference in defining the test strategy when compared to the control condition. Brownsbegger *et al*. [21] showed that individuals with higher feelings of self-reported fatigue and increases in beta band EEG activity over the previous prefrontal cortex to exercise, produced less physical workload during self exercises set by the RPE (RPE-11 and RPE-15) than in the control condition, possibly due to changes in the RPE.

According to the studies cited, it is speculated that the mental inhibitory system can suppress not only the performance on mental task, but also the motor performance. These observations imply that the mental inhibitory neural system has parts in common with the physical inhibitory system, resulting in poor performance in motor tasks. Physical inhibitory system involving the insular cortex and the posterior cingulate cortex. Consequently, insular cortex and posterior cingulate cortex can is involved in mental inhibitory system. Thus, such studies may have significant impact in improving the understanding of the effects of a mental task in motor performance.

CONCLUSION

In summary and based on the evidence presented in this narrative review, we concluded that prior acute mental exertion affects prior effectively the physiological and psychophysiological responses during the cognitive task, and performance in exercise. Additional studies involving prior acute mental exertion, exercise/sports and physical performance still need to be carried out in order to analyze the physiological, psychophysiological and neurophysiological responses subsequently to acute mental exertion in order to identify cardiovascular factors, psychological, neuropsychological associates. The use of randomized controlled trials with more sophisticated electroencephalography analyzes the correct setting of performance variables and appropriate scales of mood states are necessary to advance knowledge in this area. The results have important practical implications in the prescription of exercise/sport, as a state of prior acute mental fatigue is a common symptom of acute or chronic diseases, including myalgic encephalomyelitis (chronic fatigue syndrome), multiple sclerosis, heart failure, cancers, among others. It is noteworthy that the understanding of the possible implications that prior mental effort may have on the exercise tolerance is important for motor performance, as athletes are often subject to a combination of stressors mental and physical, during training and competitions.

LIST OF ABREVIATIONS

EMG	=	Electromyography
HR	=	Heart rate
HPA	=	Hypothalamic-pituitary-adrenal axis
RPE	=	Rate perception exertion
RR	=	Respiratory rate
SA	=	Sympathetic-adrenal
SNS	=	Sympathetic nervous system
SNP	=	Parasympathetic
VE	=	Ventilation
VO_2	=	Oxygen consumption

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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