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Research Progress and Electrophysiological Techniques of Central Fatigue in the Motor Cortex and Hippocampus

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Abstract

At present, the formation and influence of exercise fatigue (EF) have been extensively studied, but due to its complex internal mechanism and the influence of multiple factors, the mechanism of EF formation has not been fully revealed. EF includes central fatigue (CF) and peripheral fatigue (PF). Much evidence shows that the most important factors affecting exercise performance start and end in the brain, but the study of CF mechanism based on different exercise intensity is seriously lacking, so the use of mobile electrophysiology technology with high temporal resolution and strong portability to collect motor cortex and subcortical structures in different exercise modes, such as hippocampal electrophysiological indicators, can further reveal the interaction of neural networks in various brain regions under normal and/or EF conditions, thereby providing an experimental basis for EF mechanism research.

Subject Areas

Physical Education

Keywords

Exercise Fatigue, Motor Cortex, Hippocampus, Local Field Potential, Neuronal Firing

1. Introduction

In the process of exercise, the physiological processes of the body cannot continue to maintain a specific level, and cannot maintain the predetermined exercise intensity of the phenomenon is called EF, the main manifestation of which is the disorder of the body's internal environment and the decline of working capacity. EF is generally considered to be the result of the comprehensive effect of peripheral fatigue and central fatigue mechanism, and the current research on CF at home and abroad is seriously lacking, and its formation mechanism has not been fully revealed. This paper synthesizes domestic and foreign literature, aims to elucidate the research progress of cortex and subcortical structure in EF formation, and provides some ideas and enlightenment for further exploration of the mechanism of CF, mental fatigue and cognitive fatigue.

2. Motor Cortex and Hippocampus

The motor cortex is mainly composed of three parts, namely the primary motor cortex, the premotor cortex and the supplementary motor area. The primary motor cortex is the main part of the brain that generates nerve impulses that travel down to the spinal cord and control the execution of movement. Located in front of the primary motor cortex, the premotor cortex is responsible for some aspects of human motor control, including preparation for movement, sensory direction of movement, spatial direction, or direct control of part of movement, which is primarily responsible for controlling the proximal body and trunk muscles. The functions of the supplementary motor area include motion planning, motion sequence planning and coordination of the two sides of the body. The motor cortex is located in the frontal region of the anterior and posterior central gyrus, which participates in the control, planning, and execution of voluntary movements, and the primary motor cortex of the frontal lobe is the center that controls the decision-making and implementation of motor [1]. The motor cortex communicates with the hippocampus through neuronal projections in structures such as the entorhinal cortex and the cingulate gyrus. When the exercise intensity is moderate, the neural functional connections within the brain are enhanced, such as the functional activity of the hippocampus-prefrontal cortex neural network, however, the current research focuses on moderate and low-intensity exercise, and the interpretation of high-intensity exercise on intra-brain and local neural network functions is not clear.

The hippocampus is a center for stress response, plays an important role in mood, learning, and memory behavior, and is also an important area in the mammalian brain to maintain nerve regeneration. At the same time, the hippocampus, as an important part of the limbic system, is an important information intersection point, interacting with many brain regions to jointly complete various actions, behaviors and cognitive processes guided by memory [2]. Studies have shown that hippocampal volume increases with longer periods of exercise and has been found in some patients with psychiatric disorders [3]. In this way, exercise has received widespread attention as an intervention to avoid brain tissue atrophy. However, when the exercise intensity is too large, the morphology of hippocampal neuronal cells and their neural networks are significantly affected [4].

3. Research Progress on Exercise Fatigue

In the process of exercise, the body cannot maintain the predetermined exercise intensity phenomenon called EF. The generation of EF is a rather complex problem, which is the result of a comprehensive combination of various factors. As early as 1880, starting with Mosso's study of fatigue, the concept of exercise fatigue continued to change as the research deepened. In 1982, the 5th International Conference on Sport Biochemistry defined exercise fatigue as "the inability of physiological processes of the body to sustain its function at a specific level and/or to maintain a predetermined intensity". Currently, it is generally accepted that EF consists of CF and PF. CF is the result of the interaction of cortical and subcortical neural networks, where certain metabolites accumulate in muscles during locomotion or cause the downward movement of motor cortical instructions to be blocked [5]. There is growing evidence that the most important factors affecting athletic performance begin and end in the brain [6] [7]. For example, serotonin released by neurons can affect CF and motor neuron functional output; In addition, the activity of the cortico-spinal motor neuron pathway is significantly decreased during EF formation [7]. Therefore, further research is urgently needed to reveal the causal relationship between the brain's various response abilities and motor performance [7].

Fatigue, as a subjective feeling, is influenced by various factors. When considering the differences in body shape and body structure and metabolism between the sexes, women are more efficient in lipid oxidation but less efficient in anaerobic lactate metabolism, so exercise performance is inferior to men on the sustained rapid strength test, and women have a stronger sense of EF at the same load [8]. In addition, internal factors such as anxiety, sleep, or lack of energy can lead to different activation patterns in the brain and are closely related to CF [9]. External factors associated with stressful stimuli, such as sleep deprivation, also interfere with the subjective perception of fatigue, increasing CF [10]. However, in the case of extreme sports or mental stress, the body's fight-or-flight mechanism is fully activated, and metabolites such as blood lactic acid are higher than the threshold, but the fatigue of the athlete is not significant [11].

During incremental exercise, the concentration of oxygenated hemoglobin (HbO_2) in the prefrontal cortex (PFC) continued to increase; however, at EF, HbO_2 concentrations decreased markedly [12]. Since there is a positive correlation between decreased HbO_2 concentration at the PFC site and decreased muscle strength [13], it is indicated that the inhibition of PFC activity is closely related to EF [14]. In addition, as activity-related brain regions may increase with exercise intensity and increase muscle strength output instructions; thus, neural activity in the motor cortex can continue to increase with incremental movement. Some scholars have further found that in high-intensity cycling, the motor cortex electroencephalogram (EEG) oscillations are significantly correlated with electromyography (EMG) activity in time and amplitude. This study shows that using EEG, changes in cerebral cortical function can be detected during moderate to high-intensity exercise, and these EEG oscillations match the activity of working muscles. Therefore, the study of joint EEG and EMG records can be useful for further evaluating the effects of CF and PF during EF formation [15]. However, other studies have shown that oxygenation in the PFC region does not decrease during submaximal and maximal intensity exercise, whereas the motor cortex shows a significant deoxygenation trend with increasing exercise intensity and is consistent with the deoxygenation trend of working muscles [16]. The above study shows that in ascending exercise, functional changes in the motor cortex seem to better reflect the process of CF formation during exercise. During high-intensity exercise, athletes need to increase attention and somatic motion perception for the integration of vision and proprioception. Neuroimaging studies have shown that PFC can facilitate the execution of complex behaviors, including motor planning, organization, speed, direction of movement adjustment, and synthesis of multiple information. The motor cortex is mainly involved in the coordination and execution of motor sensation and function, and controls body activities through spatial sensory and motor planning. There may be interactions between multiple brain regions within the brain that jointly regulate the effectiveness of movement and the formation of fatigue perception.

Exercise intensity and duration are decisive factors in fatigue. At present, the origin and internal mechanism of CF are not clear. Conventional wisdom has been that CF results from a decline in the function of the neuromuscular pathway, but recent studies have shown that CF originates in the brain [17]. In addition to the motor cortex, many structures and regions in the brain are involved in the formation of CF, such as cardiopulmonary control (medulla and pontine brain), vision (occipital cortex, superior thalamus, and lateral geniculate), and autonomic nervous system control (insula) [17]. The multi-brain regions of the brain are interconnected through extensive neural networks to control the body's various behaviors. Therefore, functional analysis of a single brain region may not adequately reflect the mechanisms of exercise-induced fatigue. Functional connectivity (FC) is a quantitative measure used to assess brain function and is positively correlated with neurophysiological activity. Comparative studies have shown that aerobic exercise helps enhance FC of attention-related [18] and sensorimotor neural networks [19]. However, if the subject is informed in advance that he will be exercising for a long time, the functional connectivity of the central executive system will be reduced, which may be due to the body's protective mechanisms [20]. Therefore, the functional changes of neural networks between brain regions during different intensity exercise still need further study.

4. Relieve Exercise Fatigue

As mentioned above, exercise fatigue is generally considered to be the result of the combined action of peripheral fatigue and central fatigue mechanisms. Although the two kinds of fatigue have different mechanisms, they can still be alleviated by some same or similar means. First, the most effective is sleep; adequate sleep is the key to eliminating sports fatigue and restoring physical strength. In slow wave sleep (SWS), individual basal metabolism is maintained at a minimum level and anabolism is increased, which is conducive to energy storage. During sleep, cerebrospinal fluid flows into the brain tissues along the periarterial spaces and keeps exchanging with the intertissue fluid in the brain, discharging the metabolic waste of the intercellular fluid from the brain and contributing to the metabolic balance of the body. Secondly, adequate nutrition is also one of the important ways to alleviate sports fatigue. After exercise, carbohydrates, protein and other nutrients need to be increased to provide energy and renew and repair tissue. At the same time, after exercise, a large amount of fat, sugar and protein is decomposed; producing lactic acid, phosphoric acid and other acidic substances to make muscles and joints acid distention, at this time should increase the intake of alkaline food such as kelp, radish to maintain the dynamic balance of acid and base in the body.

5. Electrophysiology Techniques

In neuroscience, electrophysiology is primarily used to measure the firing activity of neurons, including voltage fluctuations caused by ionic currents within brain neurons. Electrophysiological techniques mainly include neuronal action potentials, local field potentials (LFPs) and EEG records, which can reflect individual neurons, local neuronal circuits, and overall neural network excitability changes in the brain, respectively. In sustained squat exercises, researchers first observed decreased levels of cardiovascular function, accompanied by decreased electrical activity in the frontal lobe and sensory cortex [21]. In addition, EEG data from increasing cycling subjects revealed a bidirectional regulatory function between the frontal lobe and the sensory cortex [22], EEG changes in these areas can continue into post-exercise recovery [23].

The human brain is functionally integrated with multimodal information through extensive neural network activity [24], and the analysis of neural functional activity in a single region cannot fully reflect the CNS mechanism regulation of EF. Therefore, the assessment of the resting-state network (RSN) of the brain may be more useful to explore the role of the cortex in motor execution after fatigue. RSN is defined as the functional connections of different brain regions at rest [25]. RSN modulation can show the continuous process of CNS excitability and the functional changes of neural networks in various regions. Functional magnetic resonance imaging (fMRI) studies reveal movement-induced changes in RSN, including the regulation of attention and sensorimotor networks during exercise [18]. However, despite the advantages of fMRI in spatial resolution, fMRI is due to its high cost, low temporal resolution, low mobility, and long preparation time [26]. Therefore, the use of electrophysiological means can effectively assess the effect of exercise load on RSN in multiple brain regions in real time. Evoked and event-related potentials in EEG can be used for neuro diagnosis and monitoring [27]. Since LFPs are formed in local neuronal network activity, LFPs have important reference value for evaluating individual neuronal network integrity and neural processing ability in EF. The rhythmic activity and neuronal action potential of LFPs help explain functional abnormalities in cognitive impairment, sustained attention, and stress response in EF individuals [27].

6. Summary and Outlook

The formation of EF is a complex process that includes changes in neurological, physiological, and psychological characteristics. Whether it is competitive sports or public health, fatigue has always been an important factor hindering the improvement of sports performance and inducing potential sports injuries, and EF is still one of the research hotspots in the field of sports medicine today. In this paper, we focus on the neurological and physiological effects on EF, but lack psychological characteristics. At the same time, there is a serious lack of research on this aspect at home and abroad. Perhaps the influence of psychological characteristics on EF will further explain the formation mechanism of CF. The real-time recording of the acquired multi-brain LFPs and neuronal action potential changes by multichannel electrophysiology technology can further reveal the interaction of neural networks in various brain regions under normal and/or EF conditions, thereby providing an experimental basis for the study of the mechanism of motor CF.

Project

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Conflicts of Interest

The author declares no conflicts of interest.

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