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Neurobiology of fine motor skills. Up-to-date status

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Abstract

The main goal of the current overview is to assess major trends in studying of fine motor skills neurobiology.

Materials and techniques. PubMed (MedLine), Embase databases have been used for Information search. Keywords: fine motor skills; neurobiology; neurorehabilitation. Search depth is 5 years (2016 – 2021). 12 papers that are more relevant to the topic have been chosen from the primary paper array (n=49). MAXQDA (Verbi Software GmbH, Germany) has been used for content analysis.

Results and discussion. The current state is characterized by interdisciplinary integration using both complex experimental laboratory models and modern bionic and information technologies.

Conclusion. Contemporary trends in the problem studying is the widespread utilization of information technologies and the development of approaches to neurorehabilitation with motor deficiency consideration. Fine motor skills recovery in patients with CNS lesions requires further interdisciplinary integration.

Keywords: fine motor skills; neurobiology; neurorehabilitation.

Fine motor skills are highly differentiated precise movements, predominantly of moderate amplitude and strength, where small muscles participate [1 – 3]. These movements are not innate reflexes like walking, jogging or jumping and require special development [1].

Fine motor skills involve the synchronization of hands and fingers movements with the eyes [4]. Difference in degree of movement precision of fine motor skills is defined by profession, life experience and many other factors. It promotes the intellectual growth and develops continuously throughout the human's life [1, 5]. At the same time, in presence of musculoskeletal and nervous system diseases the quality of fine motor skills could deteriorate significantly [1, 2, 6, 7].

There are several major structures in Central Nervous System (CNS) that are responsible for the fine motor skills: cerebral cortex, basal ganglia and cerebellum [8, 9]. Motor cortex of cerebral hemispheres and frontal lobe anterior to motorsensory area provide voluntary control over all skeletal muscles of the body. Our understanding of fine motor skills control centers' localization in CNS is based on experimental studies of damage on different levels of neuroaxis, as well as clinical investigations data in patients with consequences of Acute Cerebrovascular Event, Craniocerebral Trauma and other CNS lesions [7, 9, 10]. Frontal lobe area that is responsible for motor skills includes prime motor cortex, supplementary motor area and premotor cortex [8]. Primary motor cortex is located in precentral gyrus and traditionally since the classical works of Penfield W. & Jasper H. (1951) is visualized as "motor homunculus" [11]. Supplementary motor area, which is located immediately in front of prime motor cortex, takes part in posture stabilization and adjustment in addition to coordinating the movements' sequence. Premotor cortex, which is located below the supplementary motor area, processes sensory information from posterior parietal cortex and participates in sensory planning of movement and starts its programming [8, 9].

Basal ganglia are represented by the group of nuclei in brain, which is responsible for many functions, including movement. Globus pallidus and putamen are two nuclei of basal ganglia that participate in motor skills forming. Globi pallidi of hemispheres is involved in voluntary movements and putamen is in motor learning [9].

Cerebellum is very important for acquisition and development of the motor skills. It controls the fine motor skills as well as balance and coordination. Lateral part of the cerebellum hemispheres is connected with lateral corticospinal tract and participates in the planning of the extremities' motions. The intermediate part of hemisphere is connected with both lateral corticospinal tract and rubrospinal tract and responsible for coordination in distal parts of extremities including fine motor skills of fingers [8-10].

At the same time, in spite of the fact that the issues of fine motor skills neuroregulation are well studied, neurobiological bases of formation of its complex motion skills and recovery of fine motor skills in patients with focal brain lesions of different genesis are still the subject to discuss.

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Results

One of the major problems of study of neurobiological substrate of fine motor skills is the complexity of experimental data usage in clinical situation. As the result, the well-known methods of fine motor skills function assessment are being adapted. For instance, Non-Human Primate Grasp Assessment Scale (GRAS) is proposed and successfully tested based on Fugl-Meyer scale and Eshkol-Wachman motion tracking system. Using of GRAS scale allows to analyze the fullness of restoration of finger movements in primates with modelled cortical injury of motor area [12].

Another research studied the motor activitiy of distal parts of upper limbs in both phylogenetically primates and non-primates [13].

In recent years, great attention has been paid to studying of neural networks that control fine motor skills. According to Mayhew SD et al. (2017) bilateral visual-parietal motor network is responsible for precise control of hand movements. Correlation between functional Magnetic Resonance Imaging (fMRI) and bilateral network of visual, premotor, primary motor, parietal and lower frontal cortex took place during the entire feedback period. However, during stable contraction period the correlation has been found with premotor, parietal cortex and thalamus only. Thus, the authors have managed to identify the network closely associated with behavior reactions while providing visual feedback during performing fine motor movements. Whereas, in absence of this network, the broad brain activity was registered which was almost unrelated to the behavior characteristics [14].

The major researches of the last decades have provided the key proves of role of lobulus simplex of cerebelli and interposed nucleus in eyeblink conditioning and fine motor skills retardation [15].

These areas receive inputs from both mossy and climbing fibers, which transmit the signals of conditioned and unconditioned stimuli. Based on the activity of these inputs, various forms of synaptic and structural plasticity arise at the level of Purkinje cells and interneurons of the molecular layer during learning, which leads to noticeable suppression of their simple spike activity. As a consequence, the bipolar neuron disinhibits, eventually driving not unconditional but conditional closure of the eyelids through the inferior premotor red nucleus and facial motor neurons. Another mechanism is the connection of the neurons of the cerebellar vermis through the fastigial nucleus with the underlying areas of the brain, which makes it possible to affect the performance of various motor tasks.

Ontogenesis of fine motor skills has been analyzed in Hadders-Algra M (2018) study. It has been shown that starting from the early embryonal age the motor behavior is based on spontaneous neurological activity: the activity of neural networks in brainstem and spinal cord that is modulated by supraspinal activity. Supraspinal activity is initially provoked by cortical subplate and then cortical plate induces motion variation. Afferent information is used for modelling of developing neural system and in less degree for adaptation of motor behavior. On the next stage, starting from the functionally specific age, motor skills alteration begins being employed for adaptation. For sucking and swallowing this phase comes before newborn maturity. In the language, gross and fine motor skills' progression this phase appears in 3-4 months after delivery i.e. when the focus of development of primary sensory and motor cortex shifts to permanent cortical circuits.

With age and increasing number of trial and error studies, the infant improves its ability to use adaptive and effective forms of vertical gross motor behavior, fine motor skills and vocalizations belonging to the mother tongue [17].

Some of the modern works consider the role of brainstem structures in fine motor skills control [18, 19].

However, in recent years, the major progress has been achieved in utilization of artificial intellect and machine learning technologies while studying fine motor skills. In the last decades, strict hierarchy in motor neurobiology moved to the second place. The most commonly used approach is to control motor function through an optimal feedback mechanism, when any of the following functions is postulated: either loss function or function of formal definition of the problem and finding out what behavior is optimal in relation to this function. This trend is considered more progressive in neurobiology and assists to analyze specific motor behavior. Nevertheless, by this time the method has been used quite actively in fine motor skills studying. On the other hand, the controlling algorithms that are used in artificial intellect and robotics could be beneficial. Employment of numerical methods during studying of motor control mechanisms allows not only better understanding of mechanisms of fine motor skills but also choosing optimal schemes for neuro rehabilitation in patients with motor deficiency after Acute Cerebrovascular Event [20]. Figure 1 shows the contemporary view on system of motor functions' regulation including fine motor skills.

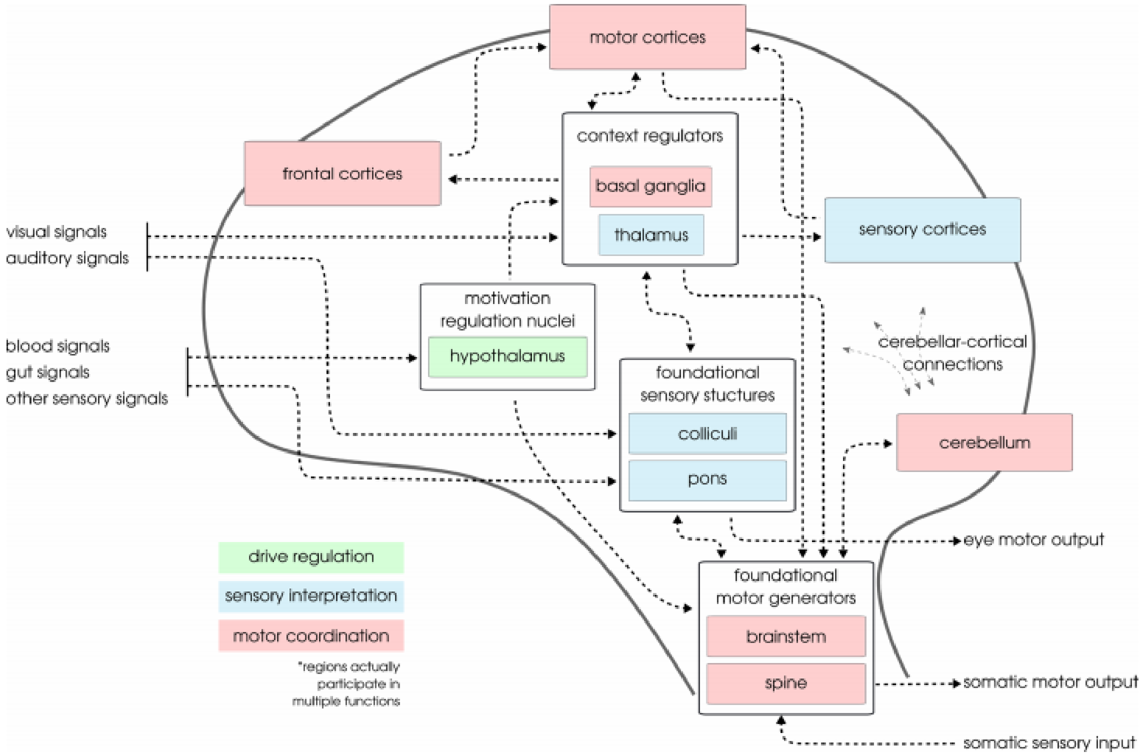

Figure 1. Neurobiological model of motor control [20]

The above principles are used in particular to create bionic prostheses and other devices designed to compensate fine motor deficits [21-23].

Conclusion:

1. Contemporary trends in the problem studying is the widespread utilization of information technologies and the development of approaches to neurorehabilitation with motor deficiency consideration.

2. Fine motor skills recovery in patients with CNS lesions requires further interdisciplinary integration.

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