Motor Control: Neurophisiological Basis and BCI Applications

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***Abstract*—This report is devoted to the review of the modern state-of-art of human motor control studies. We discuss the main neuronal processes that accomplished both the motor initiation phase and motor task execution. We also consider the possibility of creating brain-computer interfaces (BCIs) for neurorehabilitation of the motor skills of the patients after strokes and brain injuries. Finally, age-related changes in the human brain motor system functioning are considered.**

***Index Terms*—motor control, EEG, functional connectivity, age, complexity, brain-computer interface**

The motor functions of the brain are constantly used by humans in everyday life. Brain injuries, among which stroke is typical, often lead to impaired motor functions. Therefore, the rehabilitation of patients after such injuries is a significant clinical problem [1]. One of the effective ways here is the application of the methods based on brain-computer interfaces for post-stroke rehabilitation [2], [3]. In this case, it is of great interest to use not real movements (which are difficult in the case of paresis of the lower or upper limbs), but imaginary movements, which turn out to be an effective method of activating the motor cortex of the brain. This gives rise to a serious problem of automatic real-time diagnostics of imaginary motor acts, for which various approaches based on machine learning (SVM, artificial neural networks, etc) [4], time-frequency analysis [5], etc. are used.

It should be noted that motor and cognitive processes are localized in one spatial-frequency domain of neural activity of the brain, namely low-frequency α/μ (8–12 Hz) and β (15–30 Hz) brain rhythms are observed in the frontal and sensorimotor areas of the cerebral cortex, the interaction of which ensures the planning and control of the implementation of various actions. Moreover, it was found that the development of attention promotes successful motor activity [6], and episodic memory is involved in the development of motor control in animals [7]. Several studies also show that cognitive activity develops more actively with the existing need to perform more complex motor functions [8], [9].

It should be noted that cognitive and motor functions of the brain develop in close connection with each other throughout a person's life and determine the mechanisms of structural and functional reconfiguration of the brain at different stages of its development [8]. For example, decreased postural activity in childhood associated with maintaining body balance, exploring the world and learning empirically slows down the development of the cerebral cortex and cerebellum, thereby disrupting the coordination of the different rhythms of neural activity that underlie the connection between cognitive and motor activity. Therefore, developmental disorders, as well as disorders of the integrative dynamics of the brain, affect equally the deviations of both cognitive and motor functions [10]. It follows that the analysis of human motor functions is an effective method for assessing the state of the human central nervous system.

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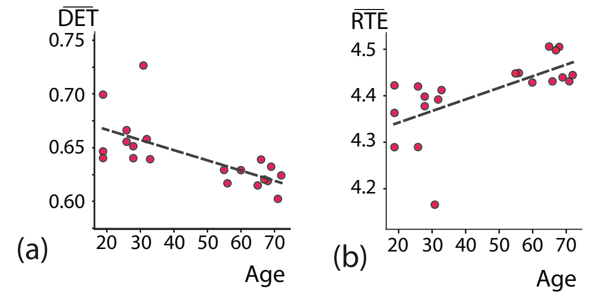

Fig. 1. DET (a) and RTE (b) versus the age of subjects. The black lines represent the linear law fitted by the linear regression.

A typical example of such a situation is age-related degeneration of the neural ensemble, which can be assessed by analyzing the brain's response to the performance of a motor act, for example, with the leading hand. In Ref. [11], we examined the effect of healthy aging on the neuronal mechanisms supporting human brain activity during motor task performance. We applied the recurrence quantification analysis (RQA) to explore the complexity of the EEG signals corresponding to motor-related brain activity in the groups of young and elderly adult subjects.

Fig. 1 shows the relationship between the age and the complexity of α oscillations assessed by RQA. Here we consider the mean values of determinism (DET) and recurrence time entropy (RTE) for each subject [12]. The presented illustrations demonstrate that (i) age-related increase of the EEG signals complexity is highly pronounced in the α-band, that is dominant in the resting state and plays a leading role in the motor-related brain activity; (ii) complexity is linearly correlated with the age. We conclude that the increased complexity of the EEG signal indicates weak neuronal plasticity degenerated under the factor of age. Therefore, the complexity

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of EEG signals in α frequency band could be considered as a relevant measure for diagnostics of age-related cognitive or motor impairments.

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