Network analysis of electrical activity in brain motor cortex during motor execution and motor imagery of elderly

Elena Pitsik
Neuroscience and Cognitive Technology Laboratory
Innopolis University
Innopolis, Russia
0000-0003-1850-2394

Nikita Frolov
Neuroscience and Cognitive Technology Laboratory
Innopolis University
Innopolis, Russia
0000-0002-2788-1907

Artem Badarin
Neuroscience and Cognitive Technology Laboratory
Innopolis University
Innopolis, Russia
0000-0002-3212-5890

Vadim Grubov
Neuroscience and Cognitive Technology Laboratory
Innopolis University
Innopolis, Russia
0000-0003-2491-2592

***Abstract*—We performed connectivity analysis of the brain motor-related electrical activity corresponding to the motor execution and motor imagery in the group of elderly subjects aged 55-76. The goal of the current study is to infer the the differences and similarities of brain motor cortex functional connectivity during executive and mental motor tasks. Particularly, we observed significant event-related desynchronization (ERD) in β-band (15-30 Hz) over the motor cortex during both motor execution and motor imagery tasks. We applied linear correlation analysis to explore functional connectivity and found that motor execution and motor imagery share the similar connectivity pattern in the β-band at the beginning of the motor-task. We conclude, that motor preparation preceding motor execution reflects the mechanisms of the motor imagery process.**

***Index Terms*—motor imagery, motor execution, neurorehabilitation, age-related effects, electroencephalography, connectivity analysis**

I. INTRODUCTION

Analysing motor-related brain activity is of strong demand due to the social significance of this topic in the area of neurorehabilitation, motor skills training, sports etc. [3], [4], [13]. Most studies refer event-related desynchronization (ERD) or suppression of the μ (8-13 Hz) and β (15-30 Hz) oscillations in the somatosensory brain cortex to as the hallmark of the motor-related activity in magneto- and electroencephalographic (M/EEG) data [10], [12], [14]. Another class of approaches includes analysis of neural interactions between motor brain areas [6].

It is known that human motor activity, such as motor imagery and motor execution, causes the emergence of functional links, which could be analyzed from the M/EEG data. The estimation of the brain functional connectivity during cognitive and motor-related tasks is usually understood in terms of synchrony within (or sometimes between) different EEG rhythms emerging in different brain regions [1], [9]. In the present paper, we demonstrate that significant ERD during motor imagery covers mostly the β frequency band. Thus, further functional connectivity analysis during motor execution and motor imagery is considered in terms of linear correlation between β-band oscillations.

Most studies use the data obtained from healthy young individuals aged 18-40. However, in the context of neurorehabilitation, it is important to explore the motor activity of the elderly groups, because the age-related changes of the brain plasticity significantly affect the neuronal processes underlying cognitive and motor brain functioning [2]. In the present paper, we perform our analysis within the group of elderly participants aged 55-76. In particular, we are interested in the brain motor cortex connectivity during motor-related tasks (motor imagery and motor execution with upper limbs).

II. MATERIALS AND METHODS

A. Dataset

The experimental dataset contained EEG and EMG data collected from 15 right-handed elderly subjects (7 female), aged 55-76, relatively healthy, having no history of nervous system injuries and never participated in BCI-based training.

During the experimental sessions subjects were sitting in a comfortable chair. In the first session they were instructed to perform two types of the motor tasks according to the commands:

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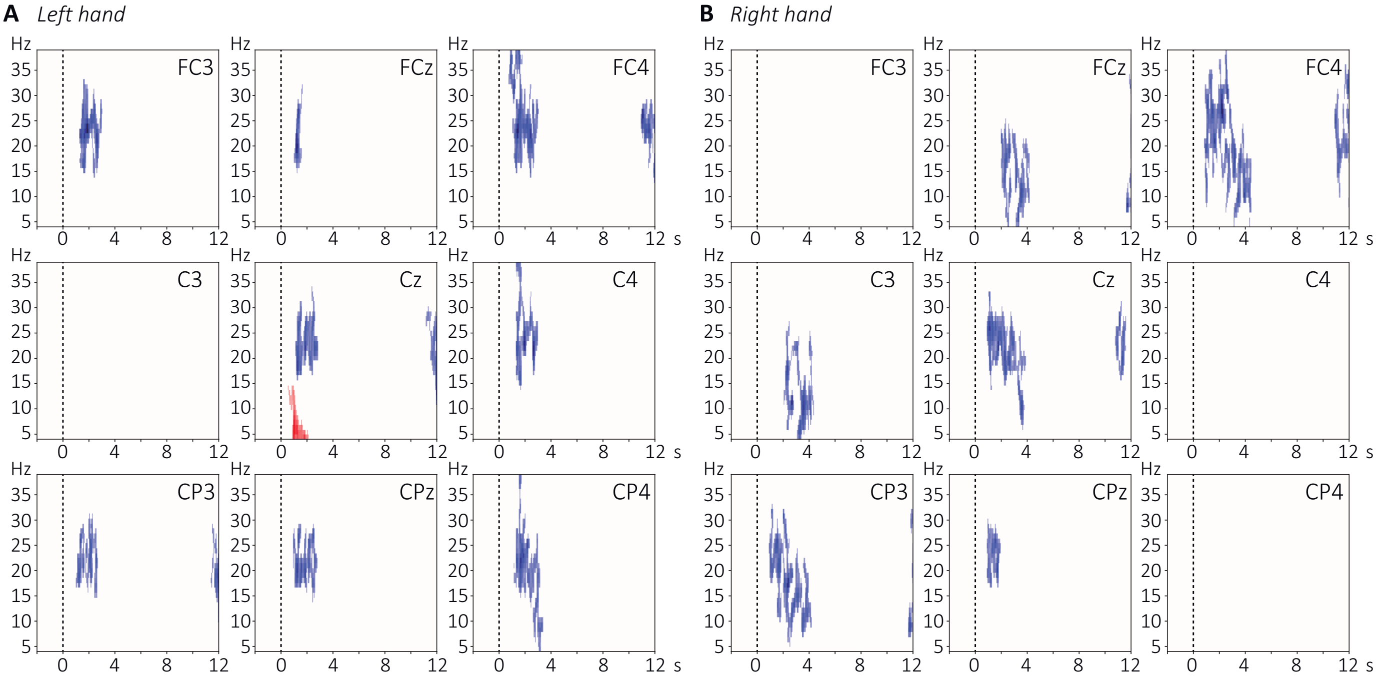

Fig. 1. Event-related desynchronization in the brain motor cortex during motor imagery with left (A) and right (B) hand.

1) first short audio signal (1 s): squeeze left hand into fist, hold it tight until the second short signal, and relax it after;
2) first long audio signal (1.5 s): squeeze right hand into fist, hold it tight until the second long signal, and relax it after.

The second signal came 4-5 s after the first signal.

During the motor imagery session only one audio signal was presented as a command for task onset.

Subjects performed 30 movements with each hand. Commands were presented randomly in order to avoid the adaptation effect. For motor execution, the intervals between two tasks (end of the previous task and beginning of the next) were randomly chosen in the range 6-8 seconds. For motor imagery, the interval between two tasks was chosen randomly in the range 7-10 seconds.

Raw EEG signals were filtered using highpass filter with cutoff frequency of 1 Hz to exclude low-frequency artifacts. Specific artifacts as eye-movements, blinking and heartbeat were removed using independent component analysis (ICA) [8]. Finally, we collected 30 epochs for each type of executed upper limb movements (18 second long, 6 seconds baseline).

B. Equipment

During the experimental session, we recorded 31-channel EEG layout using the noninvasive EEG/EMG system “Encephalan-EEGR-19/26” (Medicom MTD company, Taganrog, Russian Federation) with sampling rate fs = 250 Hz and 50 Hz Notch filter. Ag/AgCl EEG electrodes were located on the scalp according to the ”10-10” International electrode system. For further analysis, we selected the subset of 9 EEG electrodes covering the sensorimotor cortex (Fc3, Fc4, Fcz, C3, C4, Cz, Cp3, Cp4, Cpz).

To record the muscle electrical activity, we used 2 electromyography (EMG) electrodes for each hand (1 reference and 1 recording). EMG signals were used to locate the exact moments of the motor executions for each participant during the data preparation and were not used for further analysis.

C. Time-frequency analysis

We analyzed the ERD associated with motor-imagery in time-frequency domain. We used the continuous wavelet transform (CWT):

$$W(f,t_0) = \sqrt{f}\int_{-\infty}^{+\infty} x(t)\psi^*(f(t-t_0))dt \qquad (1)$$

with $*$ representing complex conjugation and ψ — the mother function:

$$\psi(\eta) = \frac{1}{\sqrt[4]{\pi}} e^{i\omega_0\eta} e^{\frac{-\eta^2}{2}} \qquad (2)$$

as a complex Morlet wavelet, which is widely used in the analysis of neurophysiological signals [7]. Here, $i = \sqrt{-1}$ and $\omega_0 = 2\pi$ – central frequency of the Morlet wavelet.

Fig. 1 demonstrates the results of time-frequency analysis of the motor-imagery EEG trials averaged over the subjects. Highlighted blue areas correspond to the significant ERD compared to the preceding baseline level according to the non-parametric cluster-based analysis with random partitions. We can see that the strongest ERD is observed in supplementary

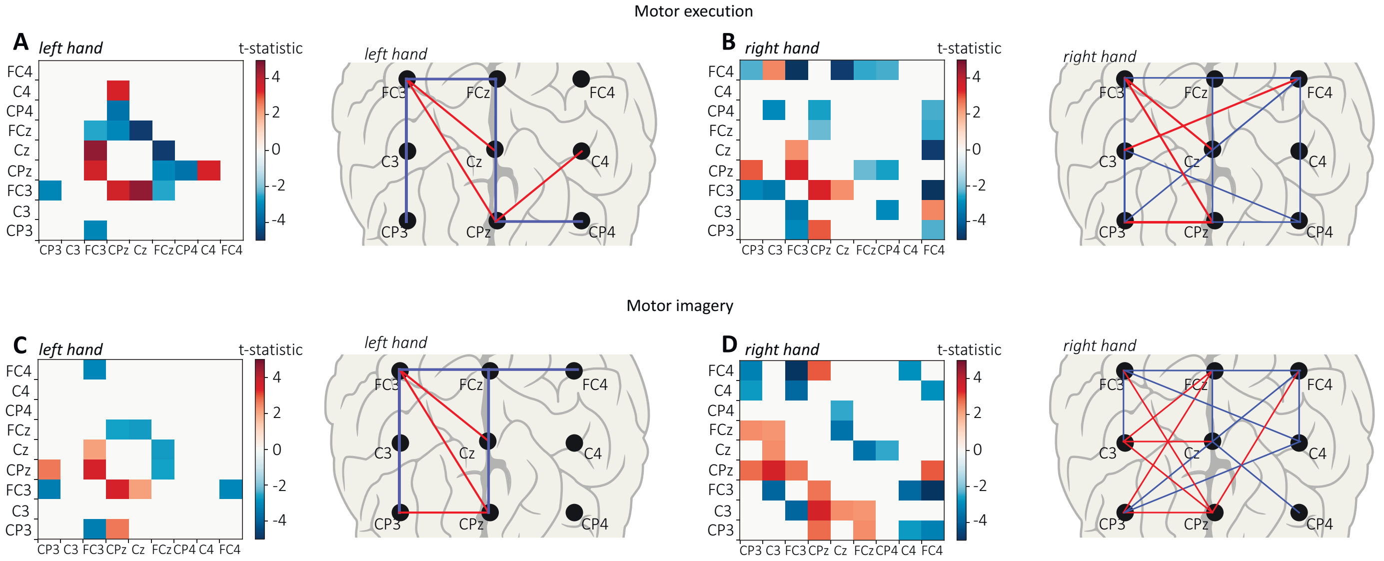

Fig. 2. Results of connectivity analysis using Pearson's correlation coefficient for motor execution (**A**,**B**) and motor imagery (**C**,**D**) with right and left hands

motor area (SMA) and primary motor area (M1) for both left (1A, channels FC4,CzC4,Cp4) and right (1B, channels FC4,Cz,C3,Cp3). Summarizing, the significant ERD takes place shortly after the signal (dashed line) and is mostly pronounced in the β-rhythm (15-30 Hz). At the same time, we observe almost complete absence of ERD clusters in the μ-rhythm (8-14 Hz), which is known to be a hallmark of motor-related activity on EEG. Therefore, for further connectivity analysis, we use time series, filtered in the β-range (15-30 Hz) using fifth-order Butterworth bandpass filter.

CWT along with the EEG preprocessing steps and filtering was performed using MNE package for Python [5].

D. Connectivity analysis

Before proceeding with connectivity analysis, we divided our subset of 9 EEG electrodes in 3 groups according to their location: right hemisphere (FC4, C4, CP4), left hemisphere (FC3, C3, CP3) and longitudinal fissure (FCz, Cz, CPz). We consider a pair of signals $X_i^{bg,task}(t)$ and $Y_i^{bg,task}(t)$ in background and task-related activity and perform pairwise connectivity analysis by measuring Pearson's correlation coefficient ρ following the equation:

$$\rho_{XY}^{bg,task}(t) = \frac{\mathrm{Cov}(X^{bg,task'}, Y^{bg,task'})}{\sigma X^{bg,task'} \sigma Y^{bg,task'}}. \qquad (3)$$

Here, $X^{bg,task'}$ and $Y^{bg,task'}$ are mean-averaged samples of $X^{bg,task}(t)$ and $Y^{bg,task}(t)$. The statistical significance of the linear correlation difference (task vs background) was evaluated using paired t-test for related samples ρ_{XY}^{task} and ρ_{XY}^{bg}. To address multiple comparison problem (MCP), permutation test was performed according to [11].

III. RESULTS

Fig. 2A,B show the results of connectivity analysis applied to motor execution with right and left hand of elderly individuals calculated in β band. One can see that during the left hand movement, significant enhance and inhibition of correlation takes place in the right hemisphere of motor cortex (coupling C4-CPz). This result is consistent with well-known contralaterality feature of motor-related brain activity. At the same time, the right hand movement is associated with couplings enhancement in left hemisphere, primary between supplementary and primary motor cortices (FC3, CP3, CPz, C3). Note the right hand movement involves highly connected functional network of the motor cortex. This could be biased by the specific feature of the right-handed subjects.

Considering functional connectivity during motor imagery Fig. 2C,D, one can see quite similar pattern formed both in right and left hand to ones observed in the case of motor execution task. The left hand motor imagery is followed by formation of statistically significant couplings in left frontal and prefrontal cortices, maintaining the same connections as during motor execution. Similarly, the right hand motor imagery is associated with correlation enhancement in left hemisphere, providing even more strong couplings pattern than in case with motor execution. The most affected areas areas are the left motor and premotor cortex (CPz, CP3, C3, Cz, FCz).

Therefore, the interactions in β-band during both motor execution and motor imagery is associated with correlation enhancement in frontal and premotor cortex. Despite the fact that the connectivity picture does not provide the pronounced contralateral pattern in case with left hand movement, we can suggest that in right-handed group of subjects the right hand motor execution as well as motor imagery affects more brain areas and establishes more couplings, providing broad connectivity pattern.

IV. CONCLUSIONS

We have analyzed connectivity network formation in brain motor cortex associated with the motor-related activity in group of the elderly subjects (aged 55-76). We considered β-band (15-30 Hz) to measure the functional connectivity in terms of the linear correlation (Pearson's correlation coefficient). Our results show that both motor execution and motor imagery share quite similar functional connectivity pattern in the brain motor cortex. Left hand motor execution and imagery involves high connectivity in the right motor and frontal areas and less in the premotor cortex. Right hand motor execution and imagery is associated with the emergence of the functional links all over the motor cortex, however with an emphasis on premotor and frontal areas.

We believe our results will contribute in the further studies of motor-related activity, especially in analysis of age-related changes in motor-related EEG pattern formation.

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