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The primary motor cortex is involved in the control of a non-motor cognitive action

Miloslav Kukleta[a], Alena Damborská[a,b,*], Robert Roman[a,b], Ivan Rektor[a,c], Milan Brázdil[a,c]

[a] *CEITEC – Central European Institute of Technology, Masaryk University, Brno, Czech Republic*
[b] *Department of Physiology, Faculty of Medicine, Masaryk University, Brno, Czech Republic*
[c] *1st Department of Neurology, St. Anne's Faculty Hospital, Masaryk University, Brno, Czech Republic*

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HIGHLIGHTS

- Late component of event related potentials can be evoked by non-target visual oddball stimuli in prefrontal areas and primary motor cortex.
- Primary motor cortex involvement concerns also situations where no overt or covered motor action is present.
- Low specialized neuronal network is suggested to be activated during cognitive operations linked to non-motor actions.

ABSTRACT

Objective: Adaptive interactions with the outer world necessitate effective connections between cognitive and executive functions. The primary motor cortex (M1) with its control of the spinal cord motor apparatus and its involvement in the processing of cognitive information related to motor functions is one of the best suited structures of this cognition-action connection. The question arose whether M1 might be involved also in situations where no overt or covered motor action is present.
Methods: The EEG data analyzed were recorded during an oddball task in one epileptic patient (19 years) with depth multilead electrodes implanted for diagnostic reasons into the M1 and several prefrontal areas.
Results: The main result was the finding of an evoked response to non-target stimuli with a pronounced late component in all frontal areas explored, including three loci of the M1. The late component was implicated in the evaluation of predicted and actual action and was synchronized in all three precentral loci and in the majority of prefrontal loci.
Conclusion: The finding is considered as direct evidence of functional involvement of the M1 in cognitive activity not related to motor function.
Significance: Our results contribute to better understanding of neural mechanisms underlying cognition.

1. Introduction

The classical view of the primary motor cortex (M1), which was based principally on direct cortical stimulation and which attributed to this structure a role in selecting the muscles and force for executing an intended movement, was, over the last two decades, substantially revised. This revision was imposed firstly by new findings demonstrating that the somatotopic organization of the M1 can be modified by peripheral changes in neuromuscular connections or motor training (Classen et al., 1998; Giraux et al., 2001; Karni et al., 1998; Pons et al., 1991; Wise et al., 1998). A second research stream brought the evidence of involvement of the M1 in cognitive functions. The original hypothesis that the M1 has an important role in the processing of cognitive information related to motor functions (Georgopoulos et al., 1989) has been supported by numerous studies which have documented the involvement of the M1 in the cognitive – motor processing during

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* Corresponding author at: CEITEC – Central European Institute of Technology, Brain and Mind Research Program, Masaryk University, Kamenice 735/5, CZ-625 00 Brno, Czech Republic. Tel.: +420 549 497 454.
E-mail address: adambor@med.muni.cz (A. Damborská).

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spatial transformations (Georgopoulos and Massey, 1987), serial order coding (Carpenter et al., 1999; Pellizzer et al., 1995), stimulus–response incompatibility (Riehle et al., 1997; Zhang et al., 1997), and in motor imagery (Lotze et al., 1999). Based on these studies we hypothesized that M1 might even be also involved during situations, where no overt or covered motor action is present. With the aim to demonstrate the suggested M1 involvement in the non-motor cognitive processing we searched for event-related potentials (ERPs) recorded in the M1 during non-target variant of visual oddball task. We chose this electrophysiological method, since it is well established in cognitive neuroscience research having also promising applications in clinical practice (Holeckova et al., 2014; Landa et al., 2014). The sequence of the main operations underlying the non-target response ought to comprise detection and cognitive discrimination of the non-target stimulus, selection and execution of the instructed response (i.e. doing nothing), and control of the accordance between the actual result of the action with its internal representation – in summary a set of predominantly cognitive tasks without direct linkage to the motor functions. To suggest the answer to the question whether the M1 loci are an integral part of the neuronal network engaged in executive control of non-motor actions, we focused on identification and comparison of ERP components elicited in different cortical regions at the end of the non-target task. To assess the linkage of the electrophysiological event and a function supposed to be running at this period of the task we decided to analyze ERPs both of correct and incorrect responses.

The salient characteristics of one subject (i.e. recording electrodes in motor and prefrontal cortices, performance difficulties of the patient manifested in a high number of incorrect responses) provided necessary data with respect to the aims of the current study.

2. Methods

2.1. Subject

The male candidate for the surgical treatment of epilepsy (19 years) was selected from a group of 18 patients employed in another intracerebral study as subject No. 9 (Damborská et al., 2016) for his unique localization of electrodes, which included the primary motor cortex in both hemispheres. His antiepileptic drug therapy was reduced during the intracerebral EEG recording to allow seizures to develop spontaneously. Standard MicroDeep semi-flexible multilead electrodes (DIXI) with a diameter of 0.8 mm, length of each recording contact 2 mm, and inter-contact intervals of 1.5 mm were used for EEG monitoring. The exact position of the electrodes in the brain was verified using post-placement magnetic resonance imaging and indicated in relation to the axes defined by the Talairach system (Talairach et al., 1967). Cortical stimulation of right precentral gyrus and left and right supplementary motor areas repeatedly elicited contractions confirming engagement of these regions in motor functions. Informed consent was obtained from the patient prior to his participation in the experiment, and the study received an approval from the Ethical Committee of Masaryk University.

2.2. Procedure

A visual oddball task with mental counting was performed in one session. Yellow capital letters X (target stimuli, T) or O (non-target stimuli) appeared repeatedly on white background in random order for 200 ms and the interstimulus interval varied randomly between 2 and 5 s. The target stimuli were five times less frequent than the non-target ones. The microswitch button pressing and mental counting was the instructed response to the T stimuli and doing nothing was the response to the non-target stimuli.

2.3. Data acquisition and processing

The EEG activity was recorded using a 64-channel Brain Quick EEG system (Micromed). The recordings were monopolar with the reference electrode placed on the right processus mastoideus. EEGs were amplified with a bandwidth of 0.1–40 Hz at a sampling rate of 128 Hz. The EEG signal was analyzed offline with the help of ScopeWin software. The artefact rejection was performed, based on visual inspection made by two experienced persons. ERPs elicited in response to non-target stimuli were analyzed on averaged artefact-free recordings with the non-target stimulus used as a trigger. Number of trials used for each average curve were as follows: 14 false alarms and 343 correct rejections. The statistical significance of ERP waves was computed between the mean amplitude observed during the baseline period (from −600 to −100 ms from the stimulus onset) and the mean value computed as a mean from the neighborhood of each point (170 ms length) after stimuli using a nonparametric Wilcoxon Rank Sum (Signed Rank) test for paired samples. One record selected from responses obtained in a cortical region from the neighboring electrode contacts was analyzed choosing the one with the largest amplitude of ERP. In our previous study (Damborská et al., 2016) the data of 18 subjects were analyzed to investigate the neuronal network engaged in processes occurring in post-movement period in visual oddball task. Contrary to that and in accordance with the current aim we searched in the present study for sites in primary motor cortex activated during non-target task variant of visual oddball task in one subject (patient No. 9 of Damborská et al., 2016 data set).

3. Results

The study was based on the analysis of event-related potentials obtained from 12 cortical regions of one subject as a response to the non-target stimulus of the visual oddball task. As is evident from Fig. 1, which presents one selected response from each region explored, the evoked responses consisted of early (up to 500 ms) and late (over 500 ms) components. The interest of the study was focused on the late component, which was present in all the explored regions, and in the majority of cases was located in a relatively stable segment of the time axis (the peak latency from 690 to 740 ms in eleven precentral and prefrontal loci, see Table 1). In half of the regions including all investigated regions of M1 cortex this component was observed as an isolated late ERP waveform. Table 1 presents the exact position of recording contacts from which the presented ERPs were derived. The calculation of the correlation coefficient in the time window from 508 to 939 ms in record pairs, which were created from all records presented in Fig. 1, showed significant r-value over 0.80 in 70% of the pairs. All of the three pairs within precentral loci reached r-values over 0.97. The mean distance between paired loci was 34.4 ± 10.8 mm, which allowed considering the analyzed waveforms as phenomena generated independently in each locus (Lachaux et al., 2003; Menon et al., 1996). The record pairs, which compared records obtained from loci in the gyrus praecentralis (area 4) on the one hand and records from the supplementary motor area (area 6), the gyrus cinguli anterior (areas 32 and 24), and the dorsolateral prefrontal cortex (areas 9 and 44) on the other hand, yielded in the time window 508–939 ms correlation coefficients ranging from 0.83 to 0.94 in nine pairs in the right hemisphere, and from 0.89 to 0.98 in three pairs in the left hemisphere. These values could be considered as evidence of transitory high-level activity