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Detection of Motor Planning and Suppression with the help of Electroencephalography

Anita G. Dieckgraeff, Axel Lindner*, Wolfgang Rosenstiel, Martin Bogdan*

Abstract—**The aim of this study was to investigate, if it is possible to detect brain activity related to motor planning and suppression with the help of Electroencephalograms (EEG), the ultimate goal being, to simultaneously measure EEG and functional magnetic resonance imaging (fMRI). Towards this end we engaged a delayed response task from an earlier fMRI study, thereby ensuring, as a first step, that the results of both EEG and fMRI would be directly comparable. Motor preparatory signals were recorded in seven subjects using 10-20-system fMRI compatible EEG equipment. The α and β frequency bands of the EEG recordings were analyzed first individually and then on the group level. Using a non-parametric statistical test, significant clusters relating to motor planning were mainly found over the motor and posterior parietal cortex of the right hemisphere. Activity corresponding with motor suppression was exhibited over the parietal and occipital cortex, located mainly medially for the lower β band (13-20Hz) and extended towards the right hemisphere for the α band. Active regions corresponded well to the ones revealed in our previous fMRI study. Simultaneous EEG and fMRI of this task in the future could thus provide us with combined information on timing (EEG), locality (fMRI) and activity characteristics (both) during motor planning and suppression.**

I. Introduction

The neuronal processes underlying movement have long been a major focus in the brain research community. With the help of modern imaging technology, questions already posed decades ago, are now reexamined with the hope of finding new and more detailed explanations for the planning processes in the brain that precede motor execution. Here we asked, which brain regions are involved in the preparation, calculation and processing of information during motor planning. How do the active brain regions cohere? Which frequency bands are engaged in motor planning processes?

Similar questions have been addressed using functional magnetic resonance imaging (fMRI) and Electroencephalography (EEG), thus obtaining information from different imaging modalities that largely differ with respect to both their spatial and temporal resolutions and, moreover, with respect to the physiological signals being measured. A new research approach is to combine these two methods for detecting brain activity, while at the same time trying to combine their advantages. Successful combinations have been demonstrated, for instance in epilepsy research [1].

This study is driven by the same motivation, the ultimate goal being to better detect motor planning and suppression by simultaneously recording EEG and fMRI, once this method is more solidly established. We designed an EEG study on basis of an earlier fMRI experiment [2]. Stimuli and tasks were quasi identical, thus allowing a comparison between the results of both imaging modalities. Specifically, the goal was to detect activity as relevant for motor planning and suppression. If comparable spatial patterns of activity could be detected using EEG, future studies with a simultaneous measurement of EEG and fMRI could further advance our ability to detect motor planning and suppression (e.g. relevant for the development of brain machine interfaces).

II. Materials and Methods

A. Participants

The group consisted of 7 healthy subjects, (2 females, 5 males). Their ages ranged from 25 to 30 years. Several subjects had prior experience with EEG experiments, although not with motor planning research. All gave written informed consent.

B. Experimental Setup

Subjects were seated approximately 57cm in front of a 100Hz computer monitor. To ensure minimal head movements they rested in a head-and-chin rest. EEG signals and eye movements were recorded throughout the experiment. In order to later reconstruct the stimuli and synchronize it with the data TTL markers were sent from the presenting software to the recording software. Additionally a phototransistor was placed on the presentation monitor, which allowed us to register the exact time of stimulus presentation together with the EEG signals.

C. General Task Design

Stimulus presentation consisted of 6 phases as shown in Fig. 1: During the fixation of 2s the subject was instructed to fixate on a cross, presented in the middle of the screen.

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A. G. Dieckgraeff is with the Department of Computer Engineering, University Tübingen, Germany (tel: +49-7071-29-74014; fax: 303-555-5555; e-mail: dieckgra@informatik.uni-tuebingen.de).

A. Lindner is with the Herti-Institute for Clinical Brain Research, Tübingen, Germany (e-mail: a.lindner@medizin.uni-tuebingen.de).

W. Rosenstiel is with the Department of Computer Engineering, University Tübingen, Germany (e-mail: rosenstiel@informatik.uni-tuebingen.de).

M. Bogdan is with the Computer Engineering Department, University Leipzig and University Tübingen, Germany (bogdan@informatik.uni-leipzig.de).

*equal contribution

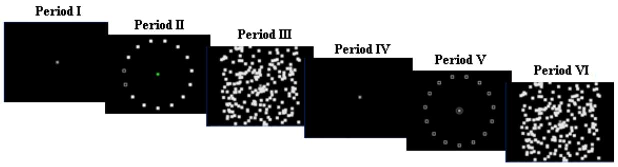

Fig. 1. The figure shows the chronological sequence of the stimulus, with it's different phases: period I, during which the subject is required to fixate, period II in which the cue and the marked goals (here darker) instruct the subject in the task, a mask (III), a delay period (IV) during which only the fixation cross is presented, and a period in which the subject is required to respond according to the task (V). The stimulus sequence is completed with the presentation of a second mask (VI).

Throughout the 1s of the cue presentation 15 possible target locations were presented in a circle, 2 of which were marked as goals. These goals were either placed on the left or the right visual hemisphere, so hemisphere specific activations could be examined. Furthermore, the fixation cross was highlighted in a color corresponding to 1 of 4 randomly assorted tasks (for more details, see II.D). The third period consisted of a mask of 0.2s, followed by the delay period during which solely the fixation cross was presented for 2s. Next, a response screen was shown for 5s that differed according to the task. Each trial ended with another mask presentation.

D. Tasks

Four tasks were presented randomly interleaved: a delayed response task (DRT), a match to sample task (M2ST), a non-match to sample task (NM2ST) and a control task (CT), as shown in Fig. 2. Below each condition is illustrated:

The DRT required the subject to plan movements to memorized goals' locations marked during cue presentation. Next, the subject had to make movements to the remembered locations during the response period. Accordingly the subject had to both memorize the goals' locations and plan actions during the delay period.

The subject was likewise required to remember the presented goals' locations during the cue period in the M2ST. These locations had to be compared to the location of newly marked goals during the response period, followed by a yes or no answer (yes: movement to brightly marked targets; no: movement to dark marked targets), considering the location of the marked goals in both periods. Hence, the subject had only to perform a memory task during the delay period since the later movement depended on the response screen. Through comparison between the delay period of the DRT and the M2ST we hoped to isolate motor planning.

The cue presentation of the NM2ST required the subject to again memorize the location of the marked goals. These had to be compared to the location of newly marked goals during the response period. In contrast to the M2ST, subjects were required to perform movements directly to the goals, whose location had been altered. According to [2] subjects seem to suppress movements to the goals which should be avoided (i.e. to the initially cued goals). Through comparison between the delay period of the DRT and NM2ST we sought to detect motor suppression.

During the CT, no goals were marked in the cue period, only in the response period. As a result, no memory or motor planning was required during the delay period. This task served as a control.

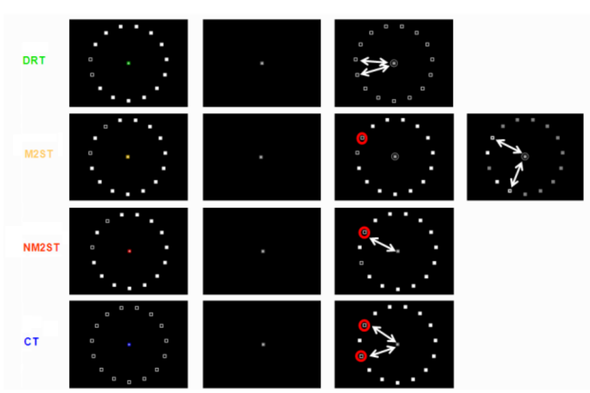

Fig. 2. The figure shows the 4 tasks used in this study (up to down: DRT, M2ST, NM2ST, CT; left to right: cue, delay and response period). In the cue period all tasks highlight two targets, except for the CT. During the response period subjects were required to make movements according to the individual task rules. These movements are indicated by the arrows. The red circles indicate goals presented in the response period that are not present in the cue period. Please note that the response period in the M2ST is comprised of two parts, first a goal comparison, followed by an answer screen.

E. EEG recording

We recorded the EEG signals using a Brain Products 32-electrode-cap. Thirty-one electrodes were arranged according to the 10-20-system, with ground placed before FZ and reference placed between FZ and CZ. All the equipment being fMRI compatible, the electrodes had predefined locations with the wiring fixated during manufacturing. Additionally a 32nd electrode was placed on the subject's back, to record electrocardiogram signals. High electrode abrasive Electrolyte-Gel was used, to ensure a good conductance between the electrodes and the subject's scalp. Since the electrodes were pin electrodes, impedances below 10Ω were only partially achieved, though all impedances were below 20Ω.

The Brain Products hardware sampled the EEG and the phototransistor signals and sent them to the Brain Products software. This software transferred the data to the BCI2000 software, which saved the data to disc.

F. Data acquisition

Every subject completed 8 runs, consisting of 48 trials each, resulting in 384 trials in total. Every task was performed 48 times by each subject, resulting in 336 trials per condition over all subjects (4 tasks * 2 locations: right/ left). Due to limitations of the EEG amplifier power supply some data had to be discarded. The signals were recorded at 500Hz with a resolution of 0.1µV.

III. DATA ANALYSIS

The data was analyzed using MATLAB and the fieldtrip toolbox. First, the markers were synchronized with the signal of the phototransistor. Subsequently, artifact ladened signals, the ECG and the phototransistor signals were removed. With the help of a highpass filter at 1Hz drifts were removed. Additionally a lowpass filter at 48Hz was applied. A baseline, consistent over all subjects, was defined during the fixation period and subsequently subtracted from all trials. With the help of an independent component analysis, eye artifacts were detected and removed from the data. Afterwards, the runs of each subject were split according to the task and newly assembled, resulting in 8 datasets per subject: DRTs with goals solely on the left and DRT with goals solely on the right visual hemisphere. We assembled M2ST, NM2ST and CT datasets accordingly.

A. Subject Analysis

First we examined each dataset of every subject using a time-frequency analysis. We applied 500ms Hanning windows and examined frequencies of 1-30Hz in 2Hz steps.

Furthermore, using a non-parametric statistical test with Monte Carlo statistics as described in [3], significant differences between tasks during the delay period were estimated. To this end we calculated a t-value for each (channel, frequency, time)-triplet, clustering samples that reached a threshold of 0.05 according to temporal, spatial and spectral adjacency. By summing up the t-values of the individual samples we obtained a positive or negative t-value for each cluster, whereas positive values indicate the first task has higher power and vice versa. On the basis of these t-values, p-values were calculated, giving an indication of its significance ($p<0.05$ assumed significant).

B. Group Analysis

After computing the spectral means over all subjects, a statistical analysis was used as in III.A, to determine significant differences on a group level.

IV. RESULTS

We pursued 2 goals during the analysis: the detection of motor planning and suppression. To this end the delay periods of the DRT and M2ST were compared in order to isolate motor planning and, accordingly, DRT and NM2ST exhibited motor suppression. In the following, we present the results of both comparisons for individual subjects and on the group level. We thereby focus on 3 frequency bands: the α band (8-12Hz), the lower β band (12-20Hz) and the higher β band (20-30Hz). Each was examined by comparing its power in the DRT relative to its power in the M2ST or the NM2ST for different groups of electrodes by calculating corresponding p-values with a non-parametric statistical test.

A. Motor planning

While performing the DRT subjects had to simply move to the remembered goals. Therefore subjects were required to perform motor planning towards the memorized goals during the delay period, whereas the M2ST merely required them to memorize the goals. Thus, by comparing the delay period in both tasks we hoped to isolate motor planning.

1.) *Subject Analysis*

The non-parametric statistical test revealed several positive and negative clusters per subject with varying significance, widely distributed over the 2s delay period. Since few clusters with $p<0.05$ were detected, we also examined clusters at $p<0.1$ in the hope of finding an overall trend related to the localization and duration of activity in the separate frequency bands. Negative clusters were mainly found over the premotor, motor and posterior parietal cortex, slightly encroaching the occipital cortex, with a tendency to the right hemisphere, see Fig. 3.

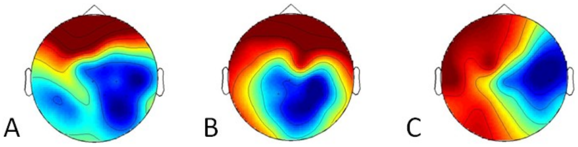

Fig. 3. Figures A - C show the distribution of t-values between -4 and 4 over the cortex whereas reddish regions depict positive and bluish regions negative t-values for the comparison of DRT and M2ST. A shows the distribution of the t-values in the α band for subject 7, B in the lower and C in the higher β Band for subject 6. As ascertainable, the activation is mainly distributed over motor and posterior parietal cortex of the right hemisphere.

2.) *Group Analysis*

By performing a group analysis we hoped that active regions in the different frequency bands would be detectable across subjects. Therefore we performed non-parametric statistical tests, which averaged the frequency according to the band of interest. Active regions in the α band were mainly located over posterior parietal and occipital cortex on both hemispheres. Active regions of the β band were mainly concentrated over premotor, motor and parietal cortex, with a tendency to the right hemisphere, see Fig. 4B-C.

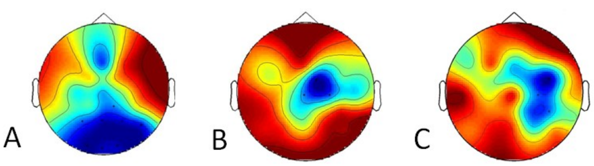

Fig. 4. Figures A - C show the distribution of t-values between -4 and 4 over the cortex whereas reddish regions depict positive and bluish regions negative t-values, calculated for the group for the comparison of DRT and M2ST. A shows the distribution of the t-values in the α band, B in the lower and C in the higher β band. The activation in the α band is distributed over posterior parietal and occipital cortex, in the β band over motor and posterior cortex of the right hemisphere.

B. Motor suppression

By comparing activity during the delay period of the DRT and the NM2ST we hoped to detect motor suppression. The delay period of both tasks was compared by means of a non-parametric statistical test and thereby detected clusters examined, according to frequency and locality. Positive clusters with a $p<0.1$ could be detected only for subject 1 and 3, in the higher β band, located over the posterior parietal and occipital cortex, as shown in Fig. 5B-C. The group analysis revealed a positive cluster in the α band located over the motor and parietal cortex of the right hemisphere, see Fig. 5A, with a drift towards the occipital cortex during the time of activation.

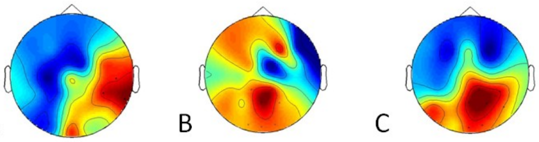

Fig. 5. Figures A - C show the distribution of t-values between -4 and 4 over the cortex whereas reddish regions depict positive and bluish regions negative t-values, calculated for the comparison of DRT and NM2ST. A shows the distribution of the t-values in the α band for the group, B and C the higher β band for subjects 1 and 3. As ascertainable, the activation (red) is mainly distributed over motor and posterior parietal cortex of the right hemisphere.

V. DISCUSSION

The aim of this study was to detect motor planning with the help of EEG and compare the findings to those of our preceding fMRI study [2]. Accordingly, experiments were conducted, consisting of four tasks: DRT consisting of motor planning and memorization, M2ST including memorization, NM2ST aiming at avoidance of memorized goals and CT as control.

A. Motor planning

Through comparing the DRT and the M2ST we hoped, that motor planning would be detectable. Several clusters were found using a non-parametric statistical test following a time-frequency analysis. Since power decrese in the α and β band indicate activity increase [4], only negative clusters were examined, since we were interested in activity corresponding to the DRT.

Two subjects showed a trend for clusters over the motor and posterior parietal cortex, as shown in Fig. 3A-B, with a tendency towards the right hemisphere, see Fig. 3C. The group analysis showed significant activity over motor, posterior parietal and occipital cortex, see Fig. 4A-C. As expected, these findings are consistent with the preceding fMRI study [2] also indicating activity in the superior parietal lobule. Therefore, simultaneous EEG and fMRI studies are expedient, with EEG giving detailed information on timing, duration and frequency ranges and fMRI on the exact location of activity.

Findings in the α band in the group analysis over posterior parietal and occipital cortex of the right hemisphere are in accordance with an MEG study [5] and most likely related to non effector-specific motor planning.

In the lower β band clusters were found in 4 of 7 subjects distributed over the right hemisphere, including motor cortex, see Fig. 3B. Some clusters varied in their location during a 500ms interval within the delay period, including premotor and occipital cortex in the activity. Examining the group analysis, regions over motor and occipital cortex could be revealed as active, see Fig. 4B.

Within the higher β band, 5 of 7 subjects revealed clusters over motor and posterior parietal cortex, extending towards premotor and occipital cortex, see Fig. 4C. The group analysis exhibited active regions over premotor, motor and posterior parietal cortex of the right hemisphere.

Our findings in the β band correspond to the study in [6] which indicates that motor planning resides mainly in the motor and posterior parietal cortex in the β band and [7], which has associated the β band to motor control.

B. Motor Suppression

Comparing DRT to NM2ST served to detect motor suppression. Two subjects revealed positive clusters over posterior parietal and occipital cortex in the higher β band, as shown in Fig. 5B-C. The group analysis detected a positive cluster over motor and posterior parietal cortex of the right hemisphere in the α band, as can be seen in Fig. 5A. Furthermore, through performing a non-parametric statistical test for individual frequencies on the group level, positive clusters could be detected in the low β band at 13Hz, located over premotor and motor cortex, and in the α band at 7Hz, ranging from frontal to occipital cortex on the right or left hemisphere according to goal presentation (right goal presentation, right cortex activation and v.v.). This is in accordance with the findings of [8], who found motor suppression in the β band, situated in frontal, premotor and parietal cortex. Most importantly, the locations are again consistent with the findings in our fMRI study [2].

VI. CONCLUSION

We successfully identified brain regions corresponding to motor planning and suppression by means of EEG. During motor planning, posterior parietal and occipital cortex showed α band activity and β band activity was found over premotor, motor, posterior parietal and occipital cortex. Motor suppression was detected over motor and posterior parietal cortex in the α band as well as over premotor, motor, posterior parietal and occipital cortex in the β band.

The similarity of active regions in this EEG study and the related fMRI study [2] supports our belief that simultaneous EEG and fMRI studies will give new insights into the neuronal characteristics of goal directed motor behavior.

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