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Alpha-band desynchronization in human parietal area during reach planning

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HIGHLIGHTS

- Posterior parietal cortex (PPC) uses frequency-specific dynamics in planning visuo-motor goal-directed tasks.
- Upper alpha band PPC activity codes for preparing goal-directed actions, whereas lower alpha band PPC activity reflects general task demands and attentional processes that are not task-specific.
- PPC activates earlier in a goal-directed action.

ABSTRACT

Objective: The symptoms with optic ataxia suggest that simple and visually guided hand movements are controlled by 2 different neural substrates. To assess the differential frequency-coded posterior parietal cortex (PPC) role in planning visuo-motor goal-directed tasks, we studied the action specificity of event-related desynchronization (ERD) in this area.

Methods: We investigated cortical activity by electroencephalography, while 16 healthy subjects performed self-paced reaching or wrist extension (control) movements. Time–frequency representations were calculated for each movement during the preparatory period.

Results: ERD dynamics in upper alpha-band indicated that preparing a goal-directed action activates contralateral PPC to the moving hand around 1.2 s before starting the movement, while this activation is later (around 0.7 s) in preparing a not-goal-directed action. The posterior dominant rhythm had peak frequency of lower alpha-band at bilateral parietal.

Conclusions: Posterior parietal cortex encodes goal-directed movement preparation through upper alpha-band activity, whereas general attention is processed via lower alpha-band oscillations.

Significance: Preparing to reach an object engages posterior parietal cortex earlier than a not-goal directed movement.

1. Introduction

Reaching for an object is a type of complex hand movement performed by humans and primates, and is often called visually guided reaching or praxis. We reach for objects with an incredibly high degree of precision in daily life. Such behavior appears to be effortless, even with unexpected perturbations such as an object relocation (Prablanc and Martin, 1992; Pisella et al., 2000). However, reaching movements require integrated information regarding the object's position and orientation to guide the hand to the object with accuracy, whereas information regarding the object's

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shape and size determines how the fingers move opposite to the thumb to grasp the object. Recent functional imaging studies that used functional MRI or PET in humans have revealed that the posterior parietal cortex (PPC) plays an important role in controlling praxis movements by continuously integrating sensory information regarding the body state and environment (Culham et al., 2006). However, these modern techniques provide temporal resolution that is insufficient for reliable quantitative analysis of activation times.

In humans and primates, motor-related activity has been successfully investigated through electroencephalographic (EEG) oscillatory activity analysis. It is well known that event-related desynchronization (ERD) in the alpha-band (8–13 Hz) starts about 1.5 s before the onset of movement (Pfurtscheller and Berghold, 1989). This activity is presumed to reflect cortical activity related to movement planning (Pfurtscheller and Lopes da Silva, 1999). Experimental data suggest that alpha ERD represents an electrophysiological correlate of activated cortical areas that is related to information processing, selective attention, and motor preparation (Van Winsum et al., 1984; Pfurtscheller, 1992; Dujardin et al., 1993, 1995). Furthermore, Pfurtscheller et al. (2000) reported that in a motor task, the upper frequency mu rhythms (10–12 Hz) reflects a more somatotopic spatial ERD pattern than the lower frequency mu rhythms (8–10 Hz). This different behavior between the lower and upper alpha-band components indicates that the lower alpha ERD reflects general task demands and attentional processes that are not task-specific, whereas the upper alpha ERD develops when movement-related information is processed; therefore, it is task-specific (Pfurtscheller et al., 2000). In addition, the posterior dominant rhythm (PDR) is an idling rhythm, indicative of a relative decrease in conscious attention or visual processing (Pfurtscheller and Aranibar, 1977). Approximately 80% of healthy adults had a PDR between 9 and 11 Hz (Kellaway, 1990).

Movement-specific ERD has been recorded not only from scalp electrodes but also subdural electrodes (Toro et al., 1994). However, only a few investigations have used this approach to study more practical and coordinated movements such as reaching, catching, or grasping (Tombini et al., 2009; Van Der Werf et al., 2010; Virji-Babul et al., 2010).

The present study aimed to clarify the involvement of PPC in movement planning and execution by revealing upper alpha-band ERD in parietal area, when reaching for an object (i.e., target- and body-related movements). Therefore, we compared reaching and simple movements to determine whether the underlying neural sources of EEG activity for these movements can be distinguished as independent.

2. Materials and methods

2.1. Participants

Subjects were 16 healthy right-handed university students (6 men, 10 women; age, 22–25 years) with normal or corrected-to-normal vision and with no reported history of neurological or psychiatric illnesses. All subjects provided an informed consent for participating in the study. The Ethical Committee of Kyoto University approved the experimental protocol (No. E-929).

2.2. Recording conditions

EEG signals from 23 Ag/AgCl surface electrodes placed on the scalp were recorded according to the 10–10 International System. For the quantitative analysis, 5 regions of interest were defined (Fig. 1), which included the left fronto-central (F3, FC1, FC3, C1, C3); right fronto-central (F4, FC2, FC4, C2, C4); midline (Fz, FCz, Cz); left parietal area (CP3, P3, P7, PO3, PO7); and right parietal area (CP4, P4, P8, PO4, PO8). Electromyograph (EMG) activity was recorded simultaneously with EEG activity from a pair of Ag/AgCl surface electrodes placed 3 cm apart over the left and right deltoid (DEL) and extensor carpi radialis muscles (ECR). Two channels of electrooculograms (EOG) were recorded horizontally (HEOG) at the external canthi of both eyes and vertical EOG (VEOG) at the upper and lower edges of the left eye. EEG, EOG, and EMG findings were recorded using a DC-EEG system (NEURO PRAX, neuroconn GmbH, Ilmenau, Germany). This DC-EEG system enables us to record without a low cut filter as done previously (Fumuro et al., 2013). EEG electrodes were referred for average signal recorded between the left and right mastoids leads. The EEG, EOG, and EMG signals were acquired at a sampling frequency of 4.096 kHz with a 1.2 kHz high-cut filter. The impedance of all electrodes was kept less than 5 kΩ as also done previously in this system (Fumuro et al., 2013).

2.3. Experimental procedures

During the EEG recording, subjects were seated comfortably in an armchair with their hands resting on a pillow. They were instructed to observe a cup (diameter 9 cm, height 7 cm) located approximately 50 cm in front of them. They were asked to reach and hold the handle of the cup with one hand in a brisk (less than 1 s), self-paced movement, and to perform approximately one reach every 10 s. The movement interval varied, and it never fixed as 10 s of interval. Each subject decided the movement interval freely without any external trigger. As a control, subjects performed a simple wrist extension with the same timing and frequency as the reaching movement. Subjects practiced the task before the recording until their performance was satisfactory.

Subjects conducted the reaching and wrist extension tasks in a set of 20 trials, and performed approximately 6 sets of each task with each hand. In reaching and control tasks, the same side of hand was employed to perform a set of each task and the other side of hand was alternatively used for each set, with a short interval to rest between the sets. Overall, subjects performed 4 different tasks within a single set: reaching with the right (Rr) or left hand (Rl) and the control with the right (Cr) or left hand (Cl). These tasks were performed in one of the 4 following sequences: (1) Rr → Rl → Cr → Cl, (2) Rl → Rr → Cl → Cr, (3) Rr → Cr → Rl → Cl, or (4) Rl → Cl → Rr → Cr. The 16 patients were randomly assigned into 4 groups ($n = 4$), with each group performing one of the above 4 task patterns. Subjects were instructed to minimize their shoulder, trunk, and head movements. The examiner observed the subject throughout the procedure to confirm a proper execution of motor task periods. During the examination, EOG and EMG were monitored closely to ensure the degree of subject's vigilance and performance.

After performing the movement tasks, subjects underwent additionally EEG recording for approximately 1–3 min while resting with their eyes-closed. The EEG recordings were used to measure the PDR.

2.4. Analysis

Data were processed offline using custom-written MATLAB (MathWorks, Natick, MA, USA) scripts (by MM, one of the authors). The data were filtered with a 60-Hz notch filter. A time–frequency analysis was performed to identify the time course of oscillatory changes before voluntary movements. The movement onset was determined by the initiation of the first EMG burst recorded from either DEL or ECR. We analyzed the EEG data recorded before the movement onset in 3-s epochs. Epochs containing artifacts were excluded from the analysis. Artifacts included muscle activity