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Electrocorticogram–electromyogram coherence during isometric contraction of hand muscle in human

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Abstract

Objective: To clarify how the primary sensorimotor and supplementary motor areas are involved in the generation of the rhythmicity of electromyogram (EMG) activity during continuous muscle contraction.

Method: We analyzed the coherence between subdurally recorded cortical electroencephalograms (EEG) and EMGs of the contralateral wrist extensor muscle during continuous isometric contraction in 8 patients with medically intractable epilepsy.

Results: In all subjects, a significant coherence between the primary motor area (M1) and EMG was observed at the peak frequency of 15 ± 3 Hz (means ± SD). In the primary somatosensory area (S1) of 7 subjects and the supplementary motor area proper (SMA proper) of 4 subjects, significant coherence with EMG was observed at 12 ± 5 and 15 ± 4 Hz, respectively. The time lags revealed by cross-correlogram were 10 ± 3, 7 ± 1 and 22 ± 8 ms in the M1, S1 and SMA proper, respectively, with the EMG lagging in all areas.

Conclusion: These findings suggest that the rhythmic activity in the SMA proper, as well as in the S1 and M1, is related to the generation of the rhythmicity of EMG activity. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Electrocorticogram–electromyogram coherence; Primary sensorimotor area; Supplementary motor area proper; Electrocorticography; Isometric muscle contraction

1. Introduction

Recent studies of coherence between electroencephalogram (EEG) or magnetoencephalogram (MEG) and electromyogram (EMG) showed cortico-muscular oscillatory communication in humans (Conway et al., 1995; Salenius et al., 1996, 1997; Brown et al., 1998; Halliday et al., 1998; Kilner et al., 1999), as well as in monkeys (Baker et al., 1997). In humans, Salenius et al. (1997) showed significant coherence in the frequency range of 15–33 Hz between MEG signals from the primary sensorimotor cortex (S1–M1) and the rectified EMG of the contralateral hand or foot muscles during isometric contraction of each corresponding muscle. Spike-triggered averaging revealed a consistent difference in the MEG–EMG time lag for hand and foot muscles. The longer time lag for foot compared with hand muscles, by about 21 ms, was in good agreement with the corresponding time difference in conduction time through the fast conducting corticospinal tract between the hand and foot. During maximal contraction, significant coherence between MEG activity from the S1–M1 and the rectified EMG was observed in the frequency range of 30–60 Hz (Brown et al., 1998).

In monkey studies, oscillations of field potentials in the primary motor cortex were coherent with EMG activity of the hand muscles in the frequency range of 20–30 Hz during the hold phase of the precision grip task (Baker et al., 1997). This finding is in agreement with the case of moderate contraction in human studies. Those rhythmic activities over the S1–M1 have been suggested to drive spinal motoneurons through the corticospinal tract and to play a role in the synchronization of EMG activity (Salenius et al., 1997; Kilner et al., 1999).

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Subdural recordings of movement-related cortical potentials (MRCPs) have indicated that the mesial frontal cortex in humans is involved in motor control (Ikeda et al., 1992; Yazawa et al., 2000). These studies showed that the mesial frontal cortex, including the supplementary motor area proper (SMA proper) and pre-SMA, generated Bereitschaftspotential almost simultaneously with the S1–M1. However, since those studies employed phasic movements as the motor task, it remained unknown whether the mesial frontal cortex was also involved in continuous muscle contraction or not.

In the present study, we recorded the cortical activity directly from the S1–M1 and the mesial frontal cortex during sustained contraction of the hand muscle in humans. The aim of this study was to elucidate how those cerebral cortices are involved in the generation of rhythmicity of EMG activity during continuous muscle contraction.

2. Subjects and methods

2.1. Subjects

We studied 8 patients with medically intractable partial epilepsy and/or brain tumor (6 females and two males aged from 15 to 35 years). All patients underwent chronic implantation of subdural electrodes for the purpose of epilepsy and/or tumor surgery. The clinical profiles of all patients are shown in Table 1.

The cortical electrical potentials were recorded with chronically implanted subdural electrodes made of platinum (Ad-Tech Co., Racine, WI). Each electrode was 3 mm in diameter, and the center-to-center interelectrode distance was 1 cm. The electrodes were placed at both the mesial and lateral surfaces of the frontoparietal lobes on the left hemisphere in 5 subjects (patients 1, 2, 4, 5 and 6), and on the right in one subject (patient 3). The remaining two subjects had electrodes only at the lateral surface of the right frontoparietal cortices (patients 7 and 8). The number of electrodes used per subject ranged from 36 to 112. This invasive technique was performed to identify the epileptogenic area by recording epileptic discharges, and to delineate the function of the cortical areas around the epileptogenic site by cortical electrical stimulation and by recording somatosensory evoked potentials (SEPs). Informed consent was obtained from all subjects after the purpose and possible consequences of the studies were explained, according to the Clinical Research Protocol No. 79, approved by the Committee of Medical Ethics, Graduate School of Medicine, Kyoto University, for patients 1, 7 and 8, and Protocol No. 98-1, approved by the Ethics Committee of the National Epilepsy Center, Shizuoka, for the remaining subjects (patients 2–6). Other neurophysiological findings of patient 1 were reported elsewhere for entirely different purposes (Ikeda et al., 1999a,b; Yazawa et al., 1997, 2000).

2.2. Cortical functional mapping

Electrical stimulation was carried out by delivering an electric current to each electrode at a progressively increasing intensity until: (1), either movements or paresthesia were elicited; (2), after-discharges occurred; or (3), the maximum stimulus intensity of 15 mA was reached. Details of the stimulation method have been described elsewhere (Lüders et al., 1987; Ikeda et al., 1992; Lesser et al., 1992). The cortical site, where the stimulation elicited muscle contraction, was identified as the ‘positive motor area’, and the area where the stimulation interfered with tonic muscle contraction or rapid alternating movements was identified as the ‘negative motor area’ (Lüders et al., 1985). For recording SEPs, electrical stimulation of the contralateral median nerve at the wrist was performed with a stimulus intensity of 20% above the motor threshold for the abductor pollicis brevis muscle.

Identification of the primary somatosensory area (S1) and the primary motor area (M1) was based on subjective sensation and positive motor responses, respectively, elicited by electrical stimulation. The central sulcus was identified based on the distribution of N20–P20 deflection of SEP in all subjects, except for patient 6, in whom SEP recording was not performed. In the mesial cortex, the SMA proper was identified by its unique response to stimulation, consisting of a predominantly tonic motor response of the upper, as well as lower limbs, either unilaterally or bilaterally, and of the trunk, neck and face (Ikeda et al., 1992). When no positive motor responses were elicited, the electrodes located posterior to the vertical anterior commissural (VAC) line on the mesial surface of the superior frontal gyrus were judged to be on the SMA proper. The VAC line was adopted as the anatomical border between the pre-SMA and the SMA proper according to previous studies (Wise et al., 1996; Zilles et al., 1996). Thus, the SMA proper was defined functionally, as well as anatomically, in the present study. If electrodes were located below the cingulate sulcus, they were assumed to be on the cingulate gyrus.

The anatomical location of the VAC line and the cingulate sulcus with respect to electrode position was determined on the lateral view of plain skull X-ray film obtained after the implantation of subdural electrodes and from the sagittal view of T1-weighted magnetic resonance images (MRIs), obtained either before or after surgery. The former was superimposed on the latter using nasion and inion as common fiducial landmarks (Ikeda et al., 1995, 1996).

2.3. Motor task

The subjects lay supine on a bed comfortably with the forearm contralateral to the implanted electrodes placed on a pillow. They were instructed to maintain the wrist in extension by continuously contracting the extensor carpi radialis (ECR) muscle for 90–120 s, and repeating this with an interval of 30 s for a total of 5–7 min. The strength