Title:

Cortical neuromagnetic activation accompanying two types of voluntary finger extension

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Abstract

We examined the amplitude and latency of movement-related cerebral field (MRCF) waveforms, the generator and afferent feedback of movement-evoked field 1 (MEF1), and the relationship between motor field neuromagnetic activity and electromyographic activity during performance of two types of voluntary index extension. Eight healthy, right-handed male volunteers participated in this study. Experiments for each subject consisted of recording of MRCFs following two types of finger movement. One (Task 1) involved voluntary extension of the right index finger to about 40 degrees. In the second (Task 2), an elastic band was placed on the right index fingertip, producing a resistance of about 1.5 times the electromyographic activity associated with the voluntary movement yielding extension to approximately 40 degrees. Peak amplitude and the ECD moment of the motor field differed significantly between the two tasks. In Task 2, the electromechanical delay from EMG onset to movement onset (77.8 ±16.2) was longer than in Task 1 (44.4±10.4). However, the latency from EMG onset to MEF1 peak was 87.6±8.5 ms in Task 2, and did not differ significantly from that in Task 1 (88.6±8.5). The ECDs of MEF1 were located significantly medial to N20m and lateral and posterior to the motor field. These findings suggest that the ECD of MEF1 is located in area 3b, but is slightly different from N20m, and that this MEF1 component activation is due not to the onset of joint movement but to that of muscular contraction.

Keywords:

MEG, Movement related cerebral field, Movement evoked field, Sensory feedback, Sensorimotor cortex, EMG

INTRODUCTION

Several studies with positron emission tomography [5, 9] and functional magnetic resonance imaging [15, 16] have revealed the brain regions probably engaged in the execution of voluntary movements. However, the nature of their generators and the afferent feedback to cerebral cortex are not fully understood. Magnetoencephalography (MEG) has revealed characteristic cerebral activation accompanying voluntary finger movement in the form of movement-related cerebral fields (MRCFs) [2, 3, 8]. The most prominent MRCF component is movement-evoked field 1 (MEF1), observed with a latency of approximately 100 ms after electromyographic onset [2, 10]. MEF1 is thought be generated mainly by proprioceptive input arising from the moving limb [2, 11]. The aim of the present study was to confirm the contribution of sensory feedback from the periphery to generation of the MEF1, and to investigate the relationship between MF amplitude and muscle activity in two types of voluntary movement in humans.

MATERIALS AND METHODS

Subjects

Eight healthy, right-handed male volunteers (ages 21- 33 years, mean 23.2 years) participated in this study. Approval of this study was obtained from the Ethics Committee of the Niigata University of Health and Welfare. Informed consent was obtained from all subjects after explanation of the nature and possible consequences of the study.

Experimental procedure

Subjects participated in the experiment (~1.0h) while comfortably seated inside a magnetically shielded room (Tokin Ltd., Sendai, Japan) with their heads firmly held using a whole-head neuromagnetometer. The standard method for recording MRCFs has been described in detail elsewhere [13]. We modified the method using a specific trigger board. All subjects performed the tasks with right hand. The subject's index finger was set up at approximately 50 degree of the metacarpophalangeal (MP) joint flexion with proximal interphalangeal (PIP) joint full extension and the MP and PIP joints of 3rd - 5th fingers were kept flexed as showed in Figure 1 and fixed to a small plate, which cuts off the LED when the finger is extended. At the cut-off, a trigger was inputted to average waveforms on-line. Experiments for each subject consisted of recording MRCFs following two

types of finger movement and the somatosensory evoked magnetic field (SEF) following median nerve stimulation. One condition (Task 1) involved voluntary extension of the right index finger with MP joint flexion from 50 to 10 degrees; in the second (Task 2), an elastic band was placed on the right index fingertip, producing a resistance about 1.5 times the electromyographic peak amplitude associated with the voluntary extension to 40 degrees determined in Task 1 (Fig 1). The range of the movement was kept asking to the subject to reach the adjustable line set up above the finger. Subjects were given a number of practices of index extension with and without resistance run prior the experiment. The rectified EMG of the extensor indicis muscle was recorded and the resistance of the elastic band was adjusted the according to the peak amplitude of the rectified EMG. The relationship between the index MP angle and the resistance force of elastic band is shown in Table 1. Each subject was instructed to move the finger at self-paced intervals with a sharp movement beginning after complete relaxation of the finger muscles. To record SEFs, the subject's right median nerve was electrically stimulated at the wrist at an intensity twice the motor threshold with a monophasic square-wave impulse of 0.2ms duration at 1.5Hz. Mean intensity for SEF was 6.9 mA (range 4.6-10.2mA).

Data acquisition

For MEG measurements, we used a whole-scalp MEG system (Neuromag 204, Elekta, Finland). This device consists of 204 planar- types, first-order gradiometers arranged in 102 pairs. This configuration of gradiometers detects the large signal just above the source current. All MEG signals were sampled at 1000Hz with bandpass filtering from 0.03 and 330 Hz. The data were obtained 2000 ms before and 1000 ms after each trigger for MRCFs and 50 ms before and 300 ms after stimulation for SEFs. The averages of 60 epochs for MRCFs in each condition and 300 epochs for SEFs were obtained separately.

A pair of Ag / AgCl electrodes was mounted over the right extensor indicis muscle. The electromyogram (EMG) was recorded to calculate the electro-mechanical delay [1] and muscle activity. The onset of EMG activity was deemed the point at which the rectified EMG exceeded three standard deviations above baseline values. EMG signals were rectified and integrated for an interval from 100ms before to 100 ms after movement onset to evaluate muscle activity.

Analysis

For analysis of MRCFs, the bandpass filter was set from 0.5 Hz to 20 Hz, with the first 200 ms (-2000 to -1800 ms) used for baseline data. We identified the motor field (MF) and MEF1, the major components just before and after movement. For analysis of SEFs, high-pass filtering was performed at 5 Hz, and the 20 ms period preceding stimulation was used for baseline data. The sources of the components of interest in the MRCFs and SEFs were estimated as the equivalent current dipoles (ECD). The ECD locations and moments were calculated using a spherical conductor model of 3D axes determined with the fiducial points, i.e. the nasion and bilateral preauricular points. We accepted ECDs with a goodness-of-fit > 90% for analysis.

The paired t-test was used to test for significant differences in integrated EMG, latencies, and amplitude of each MRCF component, as well as ECD location and moment. Differences were considered significant at 5 %.

RESULTS

Amplitude and Dipole Moment: The whole-scalp MRCF waveform detected in subject 2 in Task 1 is shown in Fig 2-a. The absolute amplitudes of MF and MEF1 were calculated by six gradiometers that detected typical MRCF waveforms. The MF and MEF1 amplitudes in each task were obtained using the same gradiometers (Fig 2-b). Representative EMG wave forms and iso-contour maps for MF and MEF1 components in the two conditions are shown in Figure 3. The rectified and integrated EMG for Task 2 (1.78±0.75 mV・ s) was significantly larger than that in Task 1 (1.03±0.47mV・ s) ($p < 0.01$). In Task 1 and Task 2, the MF and MEF1 components were specifically detected over the contralateral central region in all subjects. The mean absolute amplitude of MF in Task 2 (56.0±24.9 fT) was significantly larger than that in Task 1 (37.8±18.4 fT) ($p < 0.01$), as the result of integrated EMG. There were no significant differences in absolute amplitude of MEF1 between Task 1 (79.5±17.8 fT) and Task 2 (88.4±31.9 fT). The dipole moments at MF component were 13.2 ± 3.5 nAm in Task 1 and 19.9 ± 8.9 nAm in Task 2. This value was significantly larger in Task 2 than in Task 1 ($p < 0.05$). The

dipole moment at MEF1 in Task 1 (29.9 ± 8.3 nAm) did not differ significantly from that in Task 2 (32.5 ±7.5 nAm).

Latency: Table 2 summarizes the latencies of the MF peak, EMG onset, and MEF1 of all subjects. Figure 4a, b shows an example of a representative MRCF waveform detected from one gradiometer in each task and the relationship among EMG, trigger signal, and MEF1 peak in subject 2. Results of the paired t-test for the latencies of the MF peak from EMG onset were 20.5 ± 13.2 ms in Task 1 and 17.8 ± 11.7 msec in Task 2. There were no significant differences between two Tasks in this latency. The delay of index movement from EMG onset (electromechanical delay) in Task 2 (77.8 ± 16.2 ms) was significantly longer than the delay in Task 1 (44.4 ± 10.4 ms) ($p < 0.01$). The latencies of MEF1 peak from EMG onset, however, were 88.6 ± 13.9ms in Task 1 and 87.6 ± 8.5ms in Task 2, and not significantly different.

ECD locations: The mean ECD locations for MF and MEF1 relative to N20m in Task 1 and Task 2 are shown on axial and coronal planes in Fig. 5. In the medial-lateral direction, the mean locations of MF were significantly medial to N20m in Task 1 (10.5± 7.1 mm) and Task 2 (9.5± 3.2 mm) ($p < 0.01$). The ECD locations of MEF1 in both Tasks were significantly different from N20m only in the medial-lateral direction (6.2 ± 4.8 mm in Task 1 and 6.0 ± 5.4 mm in Task 2) ($p < 0.01$). There were no significant differences in the ECD of MEF1 between the two tasks, and these ECDs were medial to N20m and lateral and posterior to MF ($p < 0.05$).

DISCUSSION

MF activity related to effort of movement: In the present study, an elastic band was placed on the right index fingertip, producing resistance in Task 2. This difference in resistance between the tasks showed that the peak of MF amplitude and/or the strength of ECD depended on effort of movement. This finding indicated that neuromagnetic recordings are capable of localizing cortical activity associated with voluntary movement and provide a new method for study of the functional organization of human motor cortex. Furthermore, it has been postulated that the MF component reflects the primary motor cortex and the final cortico-spinal motor outflow during voluntary movement [2, 3, 12].

Amplitude and ECD moment of MEF1 peak:

Neither the amplitude nor ECD moment of MEF1 differed significantly between the two tasks. This finding indicates that MEF 1 is not generated by proprioceptive input arising from Golgi tendon organs, which have very low thresholds during muscle contraction.

Delay times from movement onset to MEF1 peak and EMG onset to MEF 1peak:

Although the latency from movement onset to MEF1 peak was 44.2±13.8 ms, MEF1 occurred approximately 88.6±13.9 ms after EMG onset in Task 1. This latency is consistent with that observed in previous studies [2, 3, 8, 10]. In our study, the electromechanical delay from EMG onset to movement onset in Task 2 was longer than that in Task 1. However, the latency from EMG onset to MEF1 peak was 87.6±8.5 ms in Task 2, and not significantly different from that in Task 1. These findings suggest that this MEF1 component activation is not due to the onset of joint movement, but to that of muscular contraction. More specifically, sensory reflexes that are involved in joint movement and/or periarticular proprioception and antagonist muscle do not activate the MEF1 waveform. Furthermore, the time from onset of muscular activation to MEF1 latency time is more than 80 ms, suggesting that MEF1 is not likely to directly reflect activity in primary sensory area 3a from the muscle spindles [14].

ECD positions: To evaluate ECD locations with reference to N20m, which is accepted as the tangential source in area 3b, in the present study we compared the ECD of MEF1 with that of N20m. Results revealed no significant difference in ECD depth, suggesting that the ECD of the MEF1 is located in area 3b similar to N20m. MEG system may be inherently biased towards detecting activations in tangential cortex and the failure of sources to localize in area 3a may be a limitation. Thus, it may be difficult to rule out additional contributions of muscle afferents in this area that are not as well detected. Many studies have reported that the dipole of MEF1 is located deeper, thus probably reflecting activation of Brodmann's area 3a during voluntary movement of the finger [2, 3, 7, 8, 10]. On the other hand, it has been reported that MEF1 during the same voluntary finger movement task was located in area 3b [14, 17], consistent with the findings of our study. Furthermore, recent studies [7, 18] using other functional imaging methods during hand movement

tasks have supported this result.

Considerations regarding the mechanism generating MEF1:

The exact role of peripheral feedback in the generation of the MEF1 is not clear, although such feedback may involve afferent input from muscle spindle receptors monitoring changes in muscle length in the involved agonist or antagonist muscle groups as well as sensory organs in joints and tendons, and even skin receptors due to mechanical stretching of overlying skin. Kristeva-Feige et al found that elimination of cutaneous inputs by anesthetic nerve block did not eliminate MEF1 responses and instead resulted in increased MEF1 amplitude [12], indicating that other receptors must be involved in the generation of MEF1. A contribution of peripheral re-afferent input to the generation of the MEF1 as well as the components of SEF has also been demonstrated [4]. In the present study, the latency of MEF1 corresponds to the onset of the muscular contraction rather than the physical motion of the finger itself by comparing movement with and without a resistive force. This finding and those of the above studies suggest that proprioceptive feedback in generation of MEF1 might be the result of activation of muscle spindles of agonist muscles sensitive to changes in muscle shape, and that MEF1 reflect re-entry via 3a projecting from muscle spindle.

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LEGENDS

Table 1

The relationship between MP angle and resistance force of the elastic band. The resistance of the task was defined prior the experiment when subjects performed index extension with or without resistance. The rectified EMG of the extensor indicis muscle was recorded and the resistance of the elastic band was adjusted the according to the peak amplitude of the rectified EMG

Table 2

The latencies of the MF peak, EMG onset and MEF1 peak from movement onset in all subjects.

Fig. 1

Illustration of the experimental tasks; Task 1: extension of the right index finger during voluntary movement to 40 degrees; Task 2: same movement as in Task 1 with an elastic band around the right index fingertip producing resistance of about 1.5 times the EMG activity associated with voluntary index extension to 40 degrees.

Fig. 2

(A) An example of whole-scalp magnetic response of movement related cerebral field (MRCF) for Task 1 in subject 2.

(B) Typical waveforms of MRCF in response to voluntary right index finger extension task (Task 1) are enlarged in a, b, and c. MF and MEF1 absolute amplitude were calculated by six gradiometers. These gradiometers detected typical MRCF waveform at all subjects.

Fig. 3

(A) Representative rectified electromyogram (EMG) and movement trigger signals for Task 1 (left column) and Task 2 (right column) in subject 5. EMG activity increased depending on the effort of movement.

(B) Iso-contour field maps for MF component in Task 1 (left column) and Task 2 (right column) in subject 5. Contour steps are 20fT. Arrows indicate the current dipole moment. The dipole moment for Task 2 (25.3 nAm) was larger than that for Task 1 (18.3 nAm).

(C) Iso-contour field maps for MEF1 component in Task 1 (left column) and Task 2 (right column) in subject 5. Contour step is 20fT. The arrows indicate the current dipole moment. ECD moment did not differ significantly between the two tasks.

Fig. 4

(A) An example of averaged MEG waveform accompanying voluntary extension of the right index finger in Task 1 and Task 2 in subject 2 (RF= readiness field, MF= motor field, MEF1= movement evoked field 1).

(B) Representative MRCF waveform, trigger signal, and electromyogram (EMG) in both tasks. Note that the delay of movement onset from EMG onset in both tasks shows the electromechanical delay of the index finger movement. The delay in index finger movement from EMG onset in Task 2 was longer than that in Task 1. The time from EMG onset to MEF1 peak did not differ significantly between the two tasks.

Fig. 5

Averaged mean equivalent current dipole (ECD) location for motor field (MF) and motor evoked field 1 (MEF1) relative to N20m for all subjects in Task 1 and Task 2 on axial and coronal planes. The error bars indicate standard deviations. The ECDs of MF were medial to N20m in both tasks. The ECDs of MEF1 were medial to N20m and lateral and posterior to MF in both tasks.

Figure

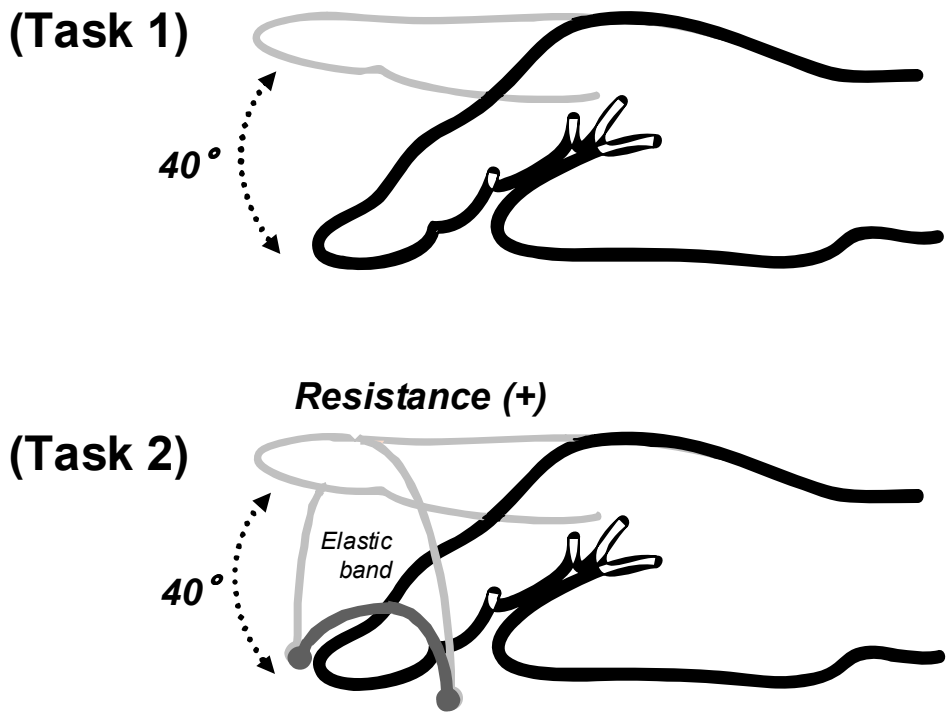


Fig.1

Figure

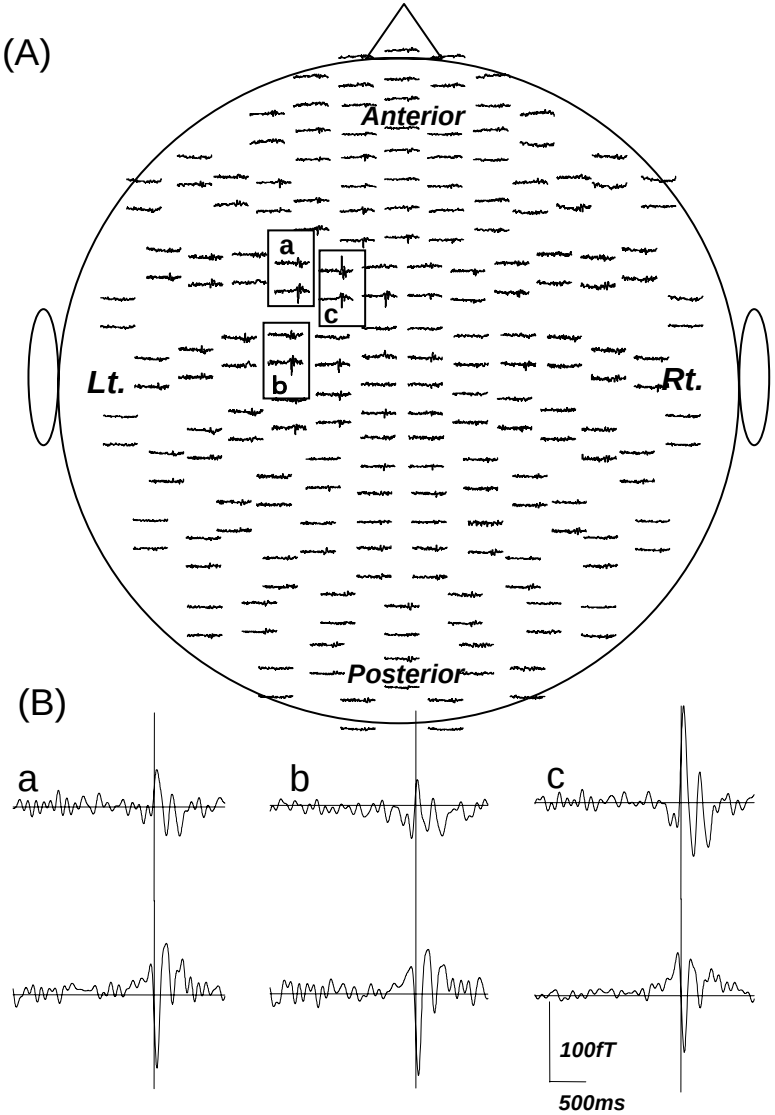
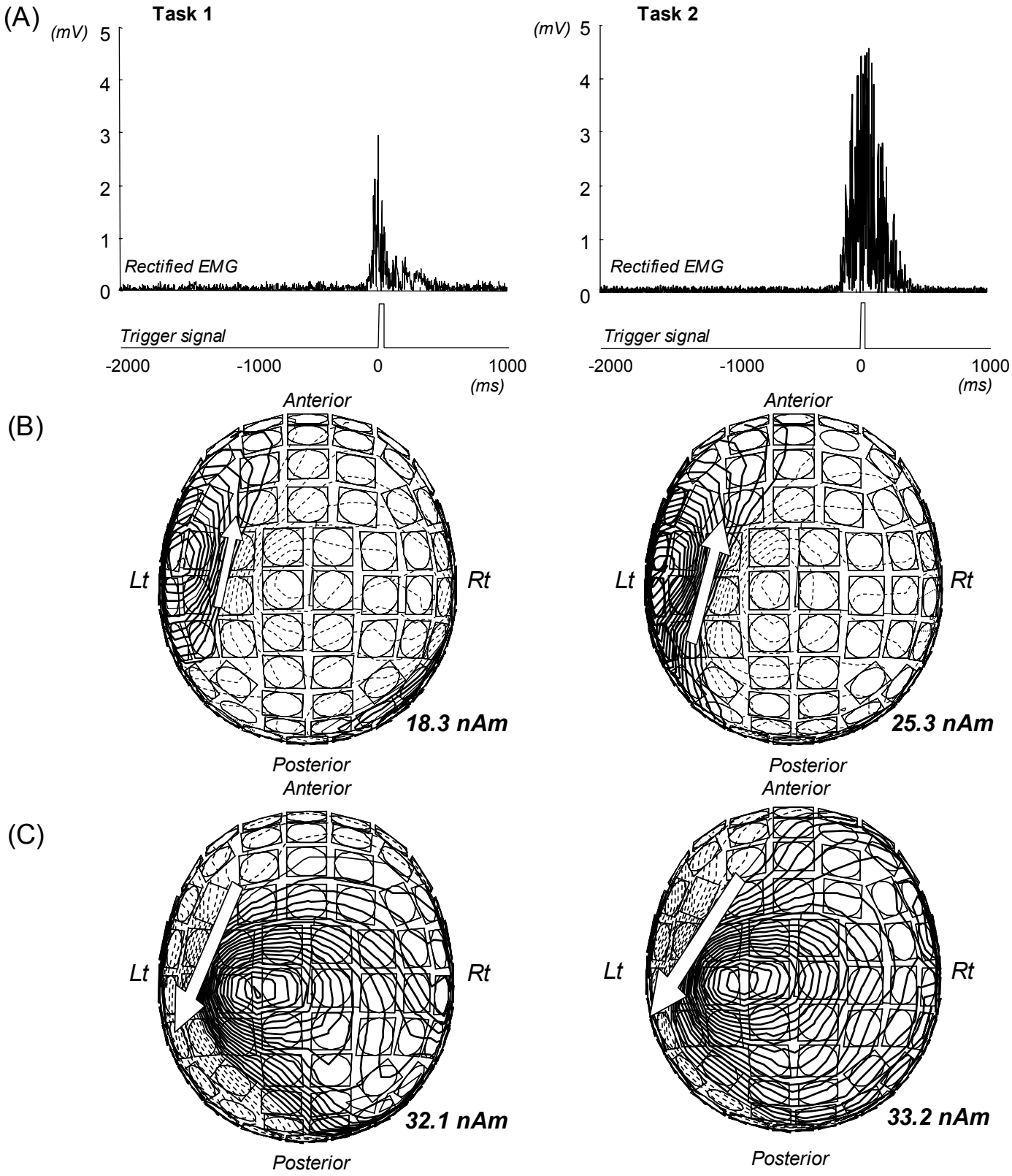


Fig. 2

Figure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Task 1
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2
1
0
Rectified EMG
Trigger signal
-2000
-1000
0
1000
(ms)
Task 2
(mV)
5
4
3
2
1
0
Rectified EMG
Trigger signal
-2000
-1000
0
1000
(ms)
(B)
Anterior
Lt
Rt
18.3 nAm
Posterior
Anterior
Lt
Rt
25.3 nAm
Posterior
(C)
Anterior
Lt
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32.1 nAm
Posterior
Anterior
Lt
Rt
33.2 nAm
Posterior

Fig. 3

Figure

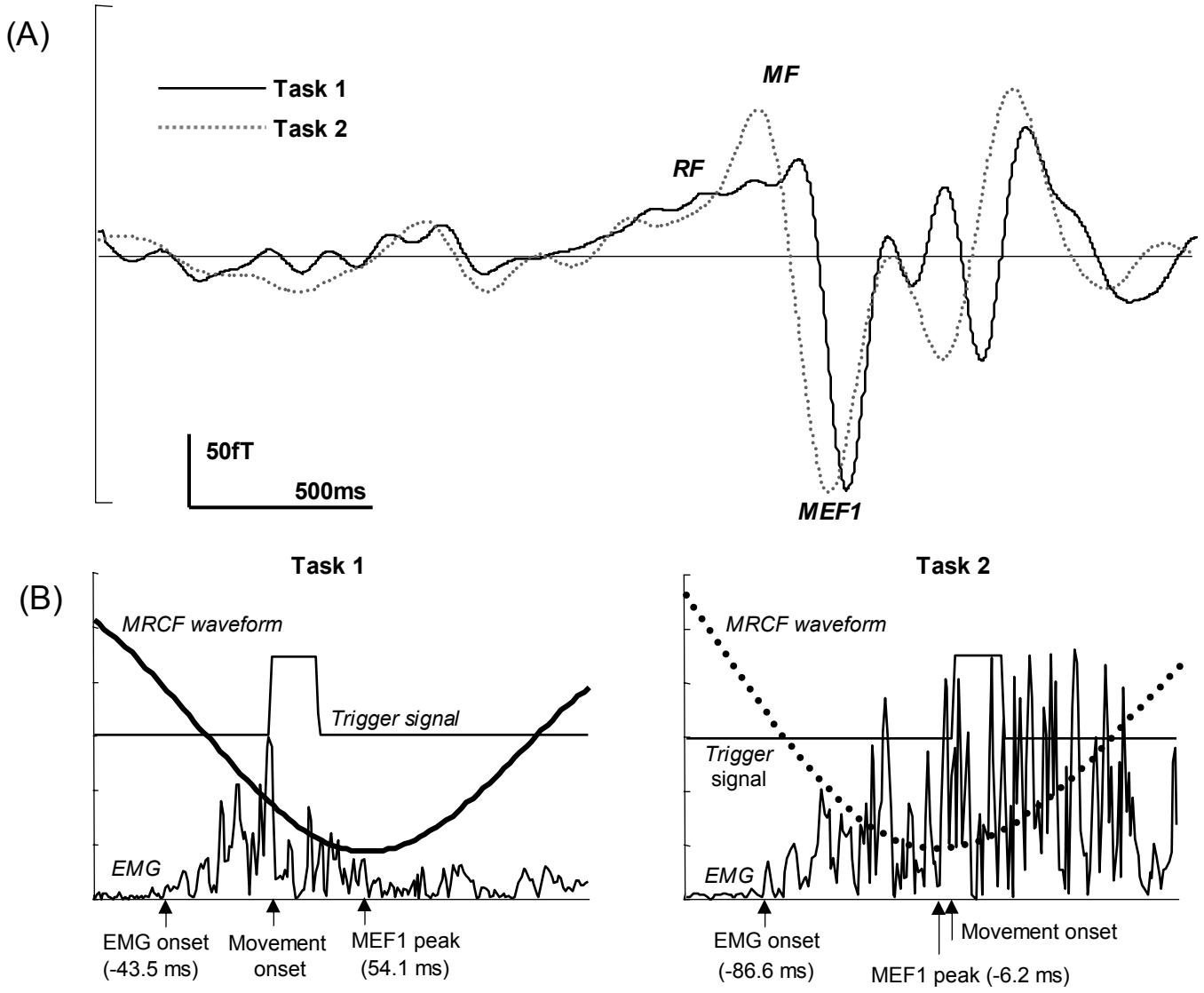
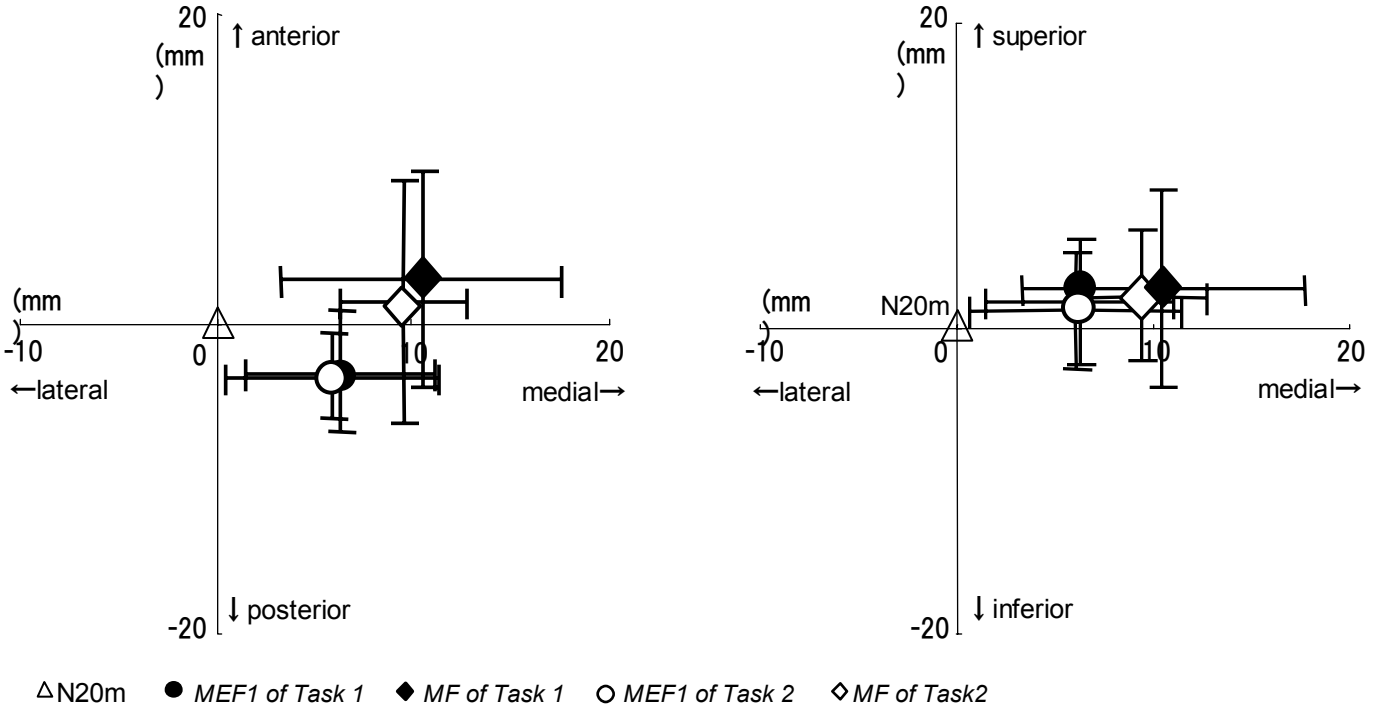

(A)
Task 1
Task 2
MF
RF
MEF1
50fT
500ms
(B)
Task 1
MRCF waveform
Trigger signal
EMG
EMG onset
(-43.5 ms)
Movement
onset
MEF1 peak
(54.1 ms)
Task 2
MRCF waveform
Trigger
signal
EMG
EMG onset
(-86.6 ms)
Movement onset
MEF1 peak (-6.2 ms)

Fig. 5

Figure


20
(mm
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←lateral
medial→
-20
↓ inferior
△N20m
● MEF1 of Task 1
◆ MF of Task 1
○ MEF1 of Task 2
◇ MF of Task2

Fig. 6

Table 1. The relationship between the index MP angle and the resistance force of elastic band.

MP flexion angle (°)	Resistance force (Kg) mean	SD
50	0.037	0.007
40	0.097	0.018
30	0.167	0.029
20	0.249	0.037
10	0.342	0.044

Table

Table 2. The latencies of the MF peak, EMG onset and MEF1 peak from movement onset in all subjects.

	MF peak (ms)		EMG onset (ms)		Movement onset		MEF1 peak (ms)	
subject	Task1	Task2	Task1	Task2	Task1	Task2	Task1	Task2
1. RH	-70.0	-115.4	-59.5	-92.5	0	0	24.9	0.3
2. KK	-77.1	-120.2	-43.5	-86.6	0	0	54.1	-6.2
3. SK	-71.4	-90.6	-42.1	-63.6	0	0	31.5	16.2
4. MM	-51.0	-82.0	-38.0	-57.0	0	0	54.0	23.0
5. NS	-46.0	-78.0	-50.0	-78.0	0	0	64.0	10.0
6. TS	-74.8	-92.3	-46.5	-74.5	0	0	30.8	10.7
7. KS	-71.0	-108.0	-51.0	-105.0	0	0	44.0	0.0
8. SS	-57.7	-78.7	-24.5	-65.4	0	0	50.2	24.5
mean	-64.9	-95.6	-44.4	-77.8	0	0	44.2	9.8
SD	11.7	16.7	10.4	16.2	0	0	13.8	11.2