Arq Neuropsiquiatr 2006;64(2-B):394-397

MAGNETOENCEPHALOGRAM RECORDING FROM SECONDARY MOTOR AREAS DURING IMAGINED MOVEMENTS

Carlos Amo[1], José R. Criado[2], Shirley M. Otis[3]

ABSTRACT - This study determined whether the activity of the secondary motor cortex (M2) could be recorded during imagined movements (IM) of the right and left hand using magnetoencephalography (MEG). Results during IM were compared with a somatosensory trial during a passive tactile stimulation in one subject. During the somatosensory trial, dipoles were detected in somatosensory (SS) and motor primary (M1) areas, scoring 94.4-98.4% for SS, 1.6-5.6% for M1 and 0% for M2. During the IM trial, dipoles were detected in SS, M1 and M2 areas, scoring 61.1-68.8% for SS, 2.6-9.3% for M1 and 28.6-29.6% for M2. These data support the hypothesis that M2 areas are activated during imagined hand movements. This study aims for the development of a diagnosis test for patients with motor deficits by evaluating the whole somatomotor network with specific interest in M2 areas.

KEY WORDS: secondary motor cortex, somatosensory areas, motor primary areas, magnetoencephalography (MEG), motor imagined movements.

Registro magnetoencefalográfico de áreas motoras secundárias durante simulação interna do movimento

RESUMO - Este estudo determina se a atividade motora secundária cortical (M2) pode ser gravada durante simulação interna do movimento (IM) das mãos direita e esquerda utilizando-se magnetencefalografia (MEG). Os resultados da simulação dos movimentos estudados foram comparados com um ensaio somato-sensorial com estimulação tactil passiva em um sujeito. Durante o ensaio somato-sensorial dipolos foram detectados em áreas somato-sensoriais (SS) e motoras primarias (MI) tendo como score 94,4-98,4% para SS, 1,6-5,6% para M1 e 0% para M2. Durante o ensaio de simulação dos movimentos também foram detectados dipolos em SS 61,1-68,8%, M1 2,6-9,3% e M2 28,6-29,6%. Estes dados evidenciam a hipótese de que as áreas M2 são ativadas durante a simulação dos movimentos das mãos. Este estudo sugere o desenvolvimento de um teste diagnóstico para pacientes com deficites motores, que avalie a rede somatomotora com interesse específico nas áreas M2.

PALAVRAS-CHAVE: áreas motoras secundárias, áreas somato-sensoriais, áreas motoras, magnetencefalografia (MEG), simulação interna do movimento.

Motor Imagery or Imagined Movements (IM) have been defined as conscious mental rehearsal of a motor act without performing any overt movement and implies that the subject feels himself executing a given action[1]. Execution and internal simulation of movements seem to follow the same temporal characteristics and use the same neural representations[2]. Studies using different neuroimaging techniques to characterize IM have revealed activation of a number of cortical motor areas[3-6] shown also by Magnetoencephalograpy (MEG)[7,8]. MEG provides high spatial and temporal resolution[9] allowing characterizing with precision the temporal sequence of different motor areas activated during IM. Based on a previous MEG protocol to evaluate motor and somatosensory function simultaneously[10], the aim of the present study is to determine whether the activity of the secondary motor cortex (M2) could be recorded by MEG during imagined movements of the hand. Thus, we propose that the analysis of IM using MEG to evaluate

Brain Research and Treatment Center. Division of Neurology. Scripps Clinic, La Jolla, CA, USA: [1]MD, PhD; [2]PhD; [3]MD. Supported by the Darlene and Donald Shiley Foundation. JRC is recipient of the Clark Fellowship in Neurophysiology.

Received 11 August 2005, received in final form 6 December 2005. Accepted 4 February 2006.

Shirley M. Otis, MD. - The Brain Research and Treatment Center - Scripps Clinic, Division of Neurology - 10666 North Torrey Pines Road - La Jolla, CA 92037 USA. E-mail: sotis@scrippsclinic.com

the whole somatomotor network could complement the diagnosis of motor function in patients with different degrees of motor deficits.

METHOD

A healthy male (39 years-old) gave his informed consent to participation in this study. MEG activity was recorded by a Magnes 2500 Whole-Head system with 148 channels (4D NeuroImaging Technologies, Inc., San Diego CA, USA) inside a shielded magnetic room while the subject underwent two different conditions. Prior to the study, the subject was instructed to execute a hand movement consisting of a wrist extension with passive flexion. In the first condition, a somatosensory trial, the subject was informed to relax his hand while feeling a pressure stimulus delivered to the index finger by a pneumatically driven mechanical system (air pressure, 15 psi). In the second condition (IM), the subject was asked to imagine moving the hand (as described above) immediately after feeling a pressure stimulus.

Inter-stimulus interval was 2 seconds and 300 trials per each hand were performed first in the left hand and then in the right hand. EMG electrodes were placed in the wrist extensor muscles in order to exclude epochs with muscular activity. Each recording was acquired with a sample rate of 678 Hz. MEG data were digitized, filtered (1-40 Hz) and averaged. Simple equivalent dipole model was used (equivalent current dipole (ECD)) to calculate the spatial localization of the neuronal currents. Only dipoles with adjust higher than 90% and confidence volume smaller than 5 cm^3 were selected. Dipoles were included in the subject MRI images with the software STA/R®[11].

RESULTS

Waveforms of averaged evoked magnetic responses obtained from the somatosensory and IM trials are shown in Figure 1. ECDs were calculated from evoked magnetic responses. To quantify the anatomical distribution of the dipoles the following cortical regions were selected:

1) M1 (Primary Motor Cortex corresponding Brodmann's Area 4).

2) M2 (Secondary Motor Cortex, Brodmann's Areas 6 and 8) including motor supplementary areas and premotor cortex.

3) S1 (Primary Somatosensory area, Brodmann's areas 1, 2, 3a and 3b).

4) S2 (Secondary Somatosensory area, Brodmann's Area 5 and 7).

The anatomical distribution of the dipoles (contralateral to the stimulus) is described in Figure 2. Somatosensory (SS) and motor primary (M1) areas were

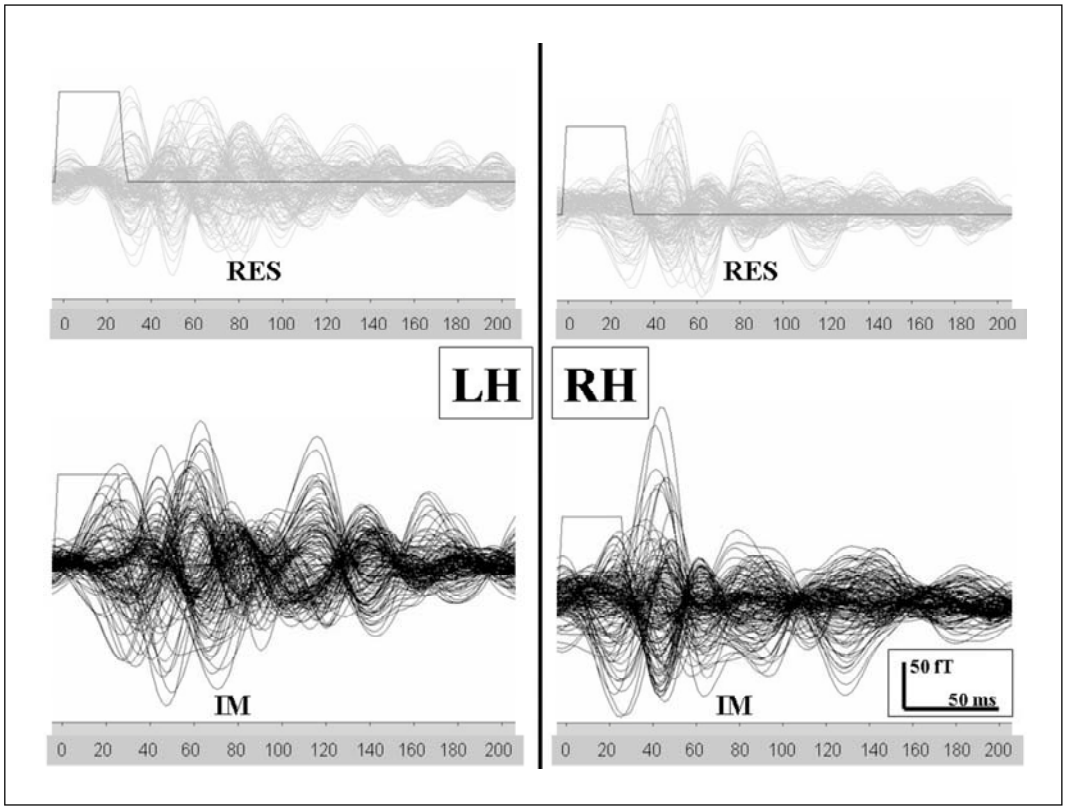

Fig 1. MEG waveforms (300 trials averaged) from evoked cortical responses in both hemispheres during a somatosensory trial (upper) and imagined movement (lower). The onset and duration of the tactile stimulus is shown at the beginning of each trace.

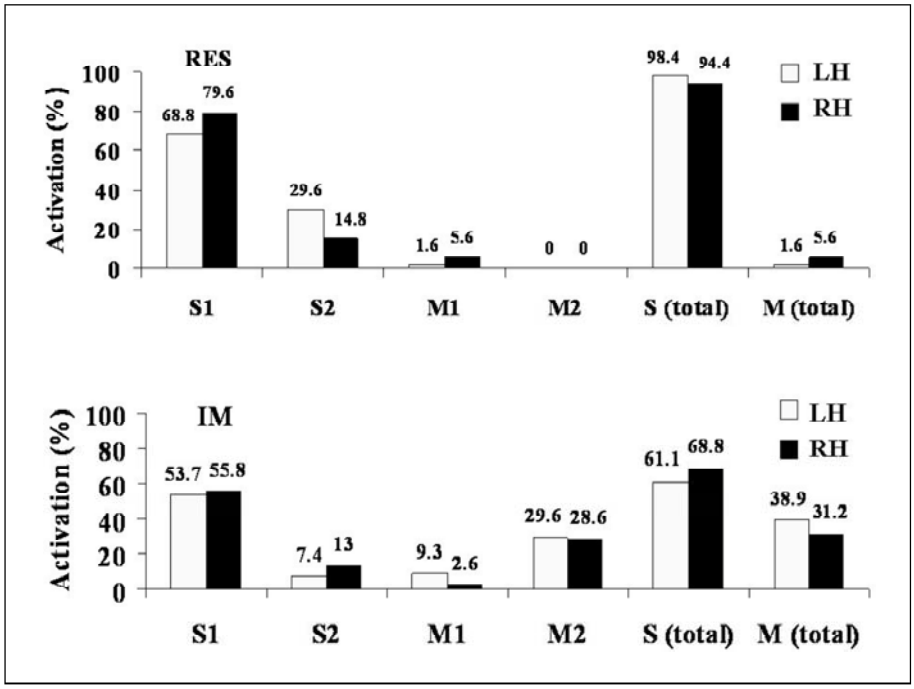

Fig 2. Dipole localization (% of total number of dipoles) from different somatosensory (S, S1, S2) and motor areas (M, M1, M2) in both hemispheres during somatosensory trial (upper) and imagined movement (lower).

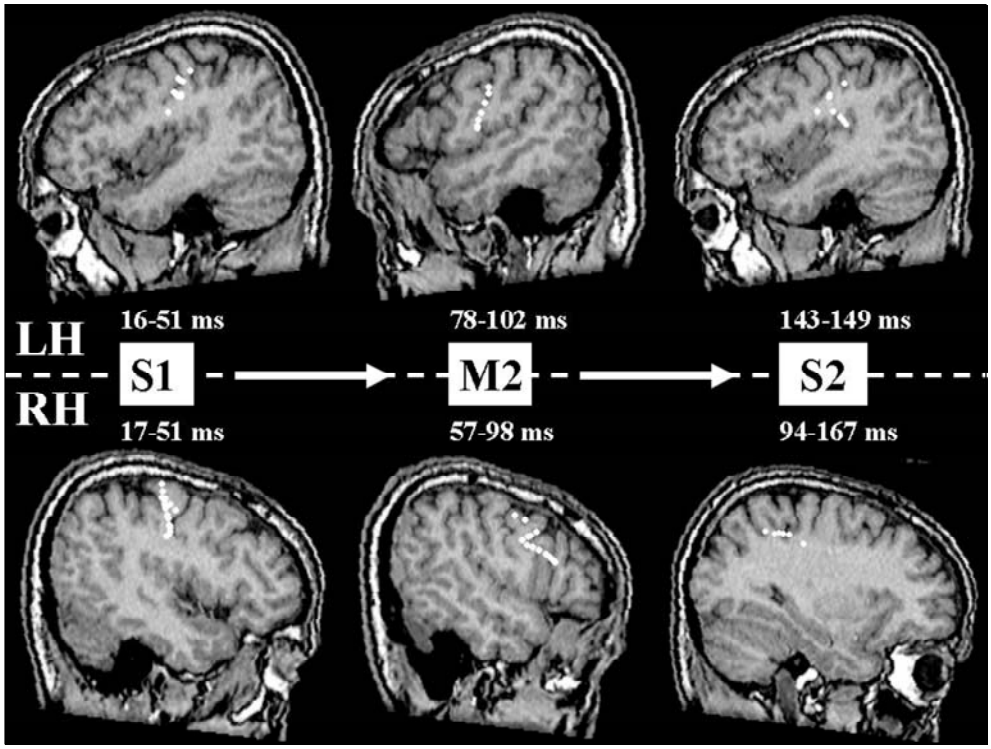

Fig 3. Dipole localization during the IM trial (white dots overlapped in a single MRI slice). Dipoles represent the temporal sequence of cortical activation during the first 200 ms after contralateral index finger stimulation.

activated during the somatosensory trial. From the total number of dipoles selected during the somatosensory trial, 94.4% were recorded in the right hemisphere (RH) and 98.4% in the left hemisphere (LH) in the SS. However, only 1.6% (LH) and 5.6% (RH) of the dipoles were recorded in M1 and no activity (0%) was recorded in M2 (Fig 2, top). From the total number of dipoles selected during the IM trial, 61.1% we-

re recorded in LH and 68.8% in the RH in the SS. Consistent with the somatosensory trial, 2.6% (RH) and 9.3% (LH) of the dipoles were recorded in M1. In contrast with the somatosensory trial, 28.6% (RH) and 29.6% (LH) of the dipoles were recorded in M2 (Fig 2, bottom).

The temporal sequence of the cortical areas activated during the IM trial was obtained from the latencies of the selected dipoles. During the first 200 ms following the tactile stimulus the temporal sequence of cortical areas activated were similar in both hemispheres. The earliest activation (16-51 ms) was predominant in S1 (contralateral to the stimulus), followed by M2 (57-102 ms) (contralateral to the stimulus), and S2 (94-167 ms) (bilateral) (Fig 3). In the somatosensory trial, the temporal sequence of the cortical areas activated was similar in both hemispheres. The earliest activation (initial 100 ms) was predominant in S1 (contralateral to the stimulus), followed by S2 (100-200 ms) (bilateral).

DISCUSSION

Findings from previous studies characterizing IM using different neuroimaging techniques[3-8] suggest that both internal simulation and movement execution shares similar neurophysiological substrates[2].

The location and latency of the MEG activity recorded in the somatosensory areas (S1 and S2) during the somatosensory and IM trials were similar. These data is consistent with previous MEG studies characterizing somatosensory evoked activity[9,10] However, our findings of S2 during IM trials could be also related to a potential role for S2 in the planning and execution of movements[5,6].

Moreover, an increase in M1 activity was found during both somatosensory and IM trials. This could be due to either somatosensory afferents innervating M1[12] or the possible role of M1 during imagined movements[8]. M2 activity was recorded during IM trials (50-100 ms), but not during somatosensory trials. The M2 activity during IM trials is consistent with previous studies[3-8].

In conclusion, this MEG study represents only an example, but shows a significant activation of M2 during IM trials (~30% of total number of dipoles recorded in the trial). The temporal sequence of activation during IM trials is as follow: S1→M2→S2. From this temporal sequence we obtained latencies that correspond to each cortical area. Further research is required with a larger sample group to validate the present results. Findings from future studies could be used for the development of a non-invasive diagnostic test for patients with motor deficits. This future diagnostic test could be used to follow up patients undergoing rehabilitation or pharmacological therapies by evaluating the whole somatomotor network with specific interest in M2 areas.

Acknowledgments – We thank Lacey Kurelowech and Patti Quint for outstanding technical support.

REFERENCES

1. Jeannerod M, Frak V. Mental imaging of motor activity in humans. Curr Opin Neurobiol 1999;9:735-739.
2. Crammond DJ. Motor imagery: never in your wildest dream. Trends Neurosci 1997;20:54-57.
3. Roland PE, Larsen B, Lassen NA, Skinhoj E. Supplementary motor area and other cortical areas in organization of voluntary movements in man. J Neurophysiol 1980;43:118-136.
4. Decety J, Perani D, Jeannerod M, et al. Mapping motor representations with positron emission tomography. Nature 1994;371:600-602.
5. Porro CA, Francescato MP, Cettolo V, et al. Primary motor and sensory cortex activation during motor performance and motor imagery: a functional magnetic resonance imaging study. J Neurosci 1996;16:7688-7698.
6. Lotze M, Montoya P, Erb M, et al. Activation of cortical and cerebellar motor areas during executed and imagined hand movements: an fMRI study. J Cogn Neurosci 1999;11:491-501.
7. Lang W, Cheyne D, Hollinger P, Gerschlager W, Lindinger G. Electric and magnetic fields of the brain accompanying internal simulation of movement. Brain Res Cogn Brain Res 1996;3:125-129.
8. Schnitzler A, Salenius S, Salmelin R, Jousmaki V, Hari R. Involvement of primary motor cortex in motor imagery: a neuromagnetic study. Neuroimage 1997;6:201-208.
9. Hämäläinen M, Hari R, Ilmoniemi RJ, Knuutila J, Lounasmaa OV. Magnetoencephalography: theory, instrumentation, and applications to non-invasive studies of the working human brain. Rev Mod Phys 1993; 65:413-497.
10. Castillo EM, Simos PG, Wheless JW, et al. Integrating sensory and motor mapping in a comprehensive MEG protocol: clinical validity and replicability. Neuroimage 2004;21:973-983.
11. Schwartz DP, Badier JM, Bihoué P, Bouliou A. Evaluation of a new MEG-EEG spatio-temporal localization approach using a realistic source model. Brain Topography 1999;11:279-289.
12. Canedo A. Functional heterogeneity of the piramidal system: corticobulbar and corticospinal tracts. Rev Neurol 2003;36:438-452.