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Functional mapping of the sensorimotor cortex: combined use of magnetoencephalography, functional MRI, and motor evoked potentials

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Abstract Combined use of magnetoencephalography (MEG), functional magnetic resonance imaging (f-MRI), and motor evoked potentials (MEPs) was carried out on one patient in an attempt to localise precisely a structural lesion to the central sulcus. A small cyst in the right frontoparietal region was thought to be the cause of generalised seizures in an otherwise asymptomatic woman. First the primary sensory cortex was identified with magnetic source imaging (MSI) of somatosensory evoked magnetic fields using MEG and MRI. Second, the motor area of the hand was identified using f-MRI during hand-squeezing. Then transcranial magnetic stimulation localised the hand motor area on the scalp, which was mapped onto the MRI. There was a good agreement between MSI,

f-MRI and MEP as to the location of the sensorimotor cortex and its relationship to the lesion. Multimodality mapping techniques may thus prove useful in the precise localisation of cortical lesions, and in the preoperative determination of the best treatment for peri-rolandic lesions.

Key words Functional magnetic resonance imaging · Magnetic source imaging · Magnetoencephalography · Motor evoked potentials

Introduction

Precise determination of the anatomical relationship between a lesion and the sensorimotor cortex can be important in deciding the appropriate surgical strategy in the peri-rolandic area. Recent advances in noninvasive localisation by the combined use of the magnetoencephalography (MEG) and imaging provide complementary information for identification of the somatosensory cortex in normal volunteers [1–6] and patients with peri-rolandic lesions [7–12]. The resulting montage of information, which can aptly be called magnetic source imaging (MSI) [7, 8, 11–14], is intriguing because it combines structure and sensory function within an image.

Many investigators have devised methods to elucidate the function of the motor cortex, including electrical stimulation [15] and positron emission tomography [16]. Current research extends MRI methods to provide information about function, the motor cortex being identified by motor tasks, in addition to concomitant anatomical information (functional MRI: f-MRI) [17–25]. Furthermore, transcranial magnetic stimulation has been developed for noninvasive stimulation of the human motor cortex [26, 27]. This technique has been used to explore the functional anatomy of the motor cortex by measuring motor evoked potentials (MEPs) following stimulation at multiple scalp sites [28–34]. We describe a multimodality mapping technique of the sen-

sorimotor cortex in a patient with a lesion in the frontoparietal region, to establish the validity of these techniques with regard to appropriate treatment.

Case report

A 40-year-old, right-handed woman was admitted with a long history of epilepsy; she experienced her first seizure at the age of 14 years. On admission, she had no neurological deficit. MRI revealed a lesion with long T1 and T2 medially in the right frontoparietal region (Fig. 1).

Magnetoencephalography

The patient underwent a localisation procedure for the hand sensory area by MSI. Our sensory mapping technique has been described previously [30]. In brief, the left thumb and little fingers were stimulated mechanically and somatosensory evoked magnetic fields (SEFs) were measured in a magnetically shielded room with a 37-channel neuromagnetometer, and the location of current dipoles of SEFs was mapped on the MRI. MSI indicated that these were located posterior to a large sulcus, which we deduced was the central sulcus (Fig. 2a, b). The lesion was medial to the hand sensory area, in both the sensory and motor areas of the cortex.

Functional MRI

Imaging was performed on a standard clinical 1.5 T system. The patient was instructed to open and close the hand in a sequential, self-paced, and repetitive manner. Multislice axial T1-weighted images were acquired before axial and coronal T2*-weighted images through the lesion; parameters for the latter were TR 80 ms, TE 60 ms, flip angle 40°, acquisition time for each slice 16 s; slice thickness was 7 mm. All subsequent analyses, including the functional maps, used 256 × 128 pixel points in a 24 × 18 cm field of view. The effect of motor activation was assessed using difference images generated by subtracting each T2* image from a baseline image.

Axial f-MRI showed a high-signal activated region, surmised to be the hand motor area (Fig. 2c). The activated region corresponded well to the precentral gyrus as determined by MEG (Fig. 2b, c).

Motor evoked potentials

Transcranial magnetic stimulation was delivered with a magneto-electric stimulator through a figure 8-shaped coil positioned with its handle pointing along the sagittal axis and the centre (the intersection of the loops) lying flat on the scalp so that it was in contact with the scalp and close to the target. Electromyographic responses were recorded from surface electrodes placed over the abductor pollicis brevis (APB) and amplified using a bandpass of 50 Hz and 3 kHz; the responses were recorded for 50 ms. At 100 % of stimulator output, stimuli were delivered to positions over the hemisphere contralateral to the muscle being recorded. Successive positions 1 cm apart were stimulated until the area where MEPs were produced was surrounded by inactive positions. Facilitation methods such as voluntary contraction were not used.

The largest APB response was obtained 1 cm anterior to C3, C4 of the international 10–20 system, where a mark with a vitamin D

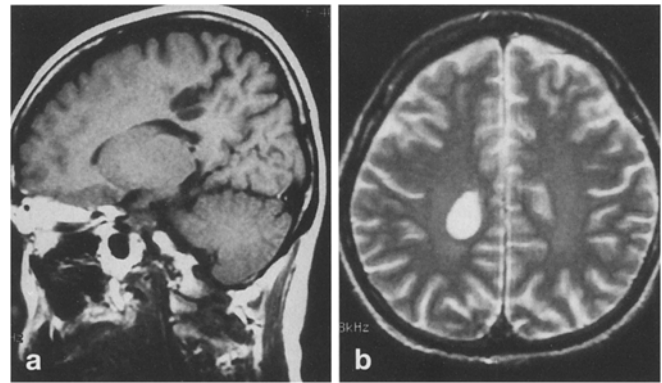


Fig. 1a, b MRI shows a lesion with long T1 and T2 medially in the right frontoparietal region. **a** T1-weighted sagittal, **b** T2-weighted axial images

capsule was placed, and subsequent MR images were then obtained. Coronal imaging clearly demonstrated the scalp points over the hand motor area on both sides (Fig. 3b), which was consistent with the f-MRI (Fig. 3a). The lesion was thus found to be within an eloquent area involving both sensory and motor cortex; radical excision of the cyst and surrounding epileptogenic area would have resulted in severe neurological deficits. Since drug treatment provided adequate seizure control, surgery was not carried out.

Discussion

The somatosensory magnetic field generated by neuroelectric activity passes through the inhomogeneities of the cerebrospinal fluid, cranium and scalp essentially unimpeded, so that MSI should localise sources of neural activity accurately. The assumed spatial accuracy of MSI with respect to landmarks on the head is within 3 mm [35]. Recently, several groups [5, 8–10, 12] have confirmed the findings of MSI by intraoperative cortical recording of somatosensory evoked potentials, thus validating the technique. MEG also has been employed to map the organisation of the auditory cortex [35], but has not been applicable to assessment of the motor cortex.

MRI has recently been used to examine human cortical function noninvasively, without the need for exogenous contrast agents [17, 21, 25]. The rationale is that deoxyhaemoglobin acts as an endogenous paramagnetic contrast agent [23, 26], changes in its local concentration leading to alterations in the T2*-weighted MR signal [22, 24, 37]. Neural activation within the cerebral cortex leads to a large increase in blood flow without an increase of similar magnitude in oxygen extraction [38, 39], which in turn causes a decrease in the capillary and venous deoxyhaemoglobin concentration, producing an increase in the T2*-weighted MR signal (blood oxygenation level-dependent contrast). The technique has been applied to functional imaging of the human motor and visual cortex at a high magnetic field of 4 T [20, 25]

Fig. 2a-c Magnetic source imaging indicating the current dipole (filled circle) in the post-central thumb (a) and little finger areas (b) following mechanical somatosensory stimulation. The mass lesion lies medial to them. c Axial f-MRI, slice corresponding to b, indicating the activated area as high signal (arrows) during a motor task. The activated region corresponds well to the precentral gyrus as determined by magnetoencephalography

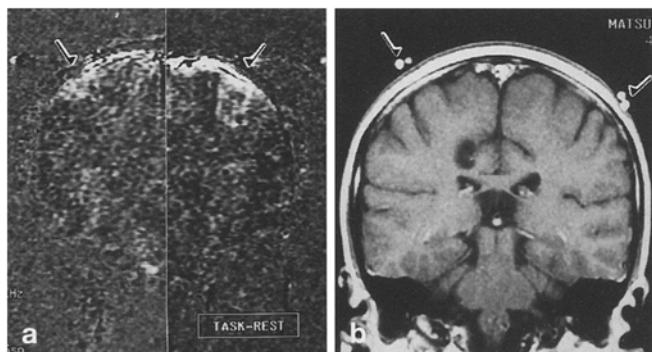
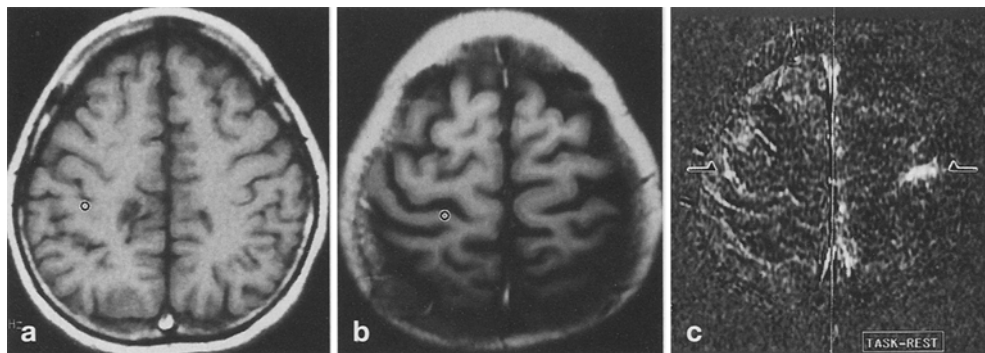


Fig. 3a Coronal f-MRI showing bilateral activated areas (arrows) during a hand grip task. **b** Corresponding coronal T1-weighted image; the scalp, where the largest motor evoked potentials from the hand were obtained, was marked with a vitamin D capsule (arrows). The hand motor areas are consistent with the findings of f-MRI

and using the high-speed echo-planar technique [7, 17, 19, 21]. In the present study, imaging was performed at a clinical field strength of 1.5 T. The large signal changes observed on f-MRI using standard clinical imagers operating at 1.5–2 T have been ascribed to direct inflow effects of the venules; this does not exclude the use of gradient-echo techniques for measurement of susceptibility changes, but indicates that inflow effects have to be carefully accounted for.

There are still limitations to clinical f-MRI. Co-operation of the patient is essential to obtain a properly activated and balanced image; if the patient has a motor deficit, the motor task will be impossible. Only a limited

number of scans may be performed in an individual case. Although further technical development may be necessary, our findings clearly demonstrate the promise of using MRI in functional mapping.

Until recently, stimulation of the human cerebral cortex was confined to the operating room [40, 41]. With the advent of transcranial magnetic stimulation, it has been possible to investigate the human motor cortex safely and painlessly [27]. It provides a noninvasive method of topographical mapping of the human motor cortex [26]. Since a figure 8-shaped coil can deliver more focal magnetic stimulus than a routine coil with a 5-mm resolution [32], it has been used to demonstrate the organisation of the human corticomotor representation in normal subjects [28–31, 33, 34]. In our patient, we mapped the hand motor area clearly on the MRI by MEPs. I in good agreement with f-MRI. However, MEPs also cannot be recorded in patients with weakness.

We found a good agreement between MEG, f-MRI and MEP as to the location of the sensorimotor cortex and its relationship to the lesion. Although there are still some disadvantages of each method in practical use, combined use of these mapping techniques appears to overcome these difficulties. Multimodality mapping techniques may thus be useful in the more precise localisation of cortical lesions and helpful in determining the best form of treatment of peri-rolandic lesions.

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BOOK REVIEW

French, R.: William Harvey's Natural Philosophy. Cambridge University Press. (ISBN: 0-521-45535-9), Hardcover £ 40.00.

This book, a study of a major change in natural philosophy written by a professional historian for his peers, is not for the casual historian or philosopher of science. Dr French, a master of his subject and his sources, addresses in a closely reasoned and richly annotated narrative the origins of Harvey's natural philosophy, how it determined his approach to a problem, the structure of his results and their expression and led him to postulate, following his studies of the action of the heart, that the blood must circulate. It also largely determined the way in which he marshalled his evidence and presented his case in *De motu cordis*. The author then goes on to consider, in perhaps the most important section, how individuals and their institutions with different philosophies both home and abroad responded to Harvey's discovery and the mechanisms that fostered or inhibited the development of a consensus. For without some form of consensus the concept of a circulation would have remained an unorthodox view and natural philosophy and medicine as a whole would have remained

unchanged. Among the factors determining that response were the use of the formal structures of argument and expression familiar to educated men and the influences brought to bear on individuals through their membership of medical, collegiate or religious group. The author reminds us that for most of Harvey's contemporaries the main question was whether they could or needed to reconcile his doctrines with more important matters occupying their minds: personal salvation; the correct interpretation of God's will; the coming millenium and so forth. It is with hindsight that Harvey's discovery is seen as fundamental to a later development of "biomedical science". He goes on to consider at some length Descartes's adoption, in modified form, of Harvey's doctrines and the radical differences in their natural philosophies, the impact this had on their understanding from the 1630s onwards and how it influenced their acceptance or rejection.

There is much of interest to be learned from Dr French's observations on the motives that led individuals (and institutions) to reject Harvey's doctrines, ranging as they did from the early and implacable opposition of Primrose to the eminent anatomist Riolan, who as Dean of the Medical Faculty of Paris had, as Harvey observed, a duty to see that Galenic medicine was kept in good repair. A major stumbling block to

the acceptance of Harvey's account of a total circulation was that it seemed to make nonsense of bloodletting as a therapeutic manoeuvre, based as it was on a Galenic concept of anatomy. Riolan, compelled by a growing consensus to accept some form of circulation, attempted to reconcile this with what he previously believed and to turn compromise to his advantage by making claims for his *New Circulation*. In his reply, Harvey, now over 70 and used to seeing his doctrine mutilated or dismembered as often as accepted, made one last attempt to promote it. He pretended disdain for his critics but his language was bitter. The author concludes the last section of the book, dealing with the development of an experimental philosophy, with a memorable summary: "the important event in the Harvey business was not that the light of Harvey's truth could no longer be resisted, but that it came to be thought that truth, or the best possible approximation to it, could be discerned by experiment". This was his true legacy.

A short review cannot do full justice to a book described by its publishers as the most extensive discussion of Harvey to have been published for over 25 years. Those who take the trouble to read it will be richly rewarded.

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