The spatial correspondence of fMRI activation and EEG sources during repeated painful stimulation

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We analyzed the spatial correspondence of fMRI activation clusters and the sources of somatic evoked potentials during repeated painful intracutaneous electrical stimulation. Ten right-handed men underwent one EEG recording (88 channels) and one 1.5-Tesla fMRI recording with a block design. The shortest distances between EEG sources and fMRI clusters were found in the mesial frontal cortex and in the contralateral parietal operculum, indicating a good match between the electrocortical and hemodynamic responses, particularly in these two cortical regions.

Introduction

Previous fMRI studies of acute pain showed activation in the insula, the secondary somatosensory area (SII), the cingulate cortex, the supplementary motor area (SMA), the premotor cortex and the posterior parietal cortex and other cortical and subcortical regions [1-3]. The electrical potentials and neuromagnetic fields evoked by painful stimuli also showed sources in the left and right SII and in the cingulate cortex [4-6]. The elucidation of the spatial correspondence between electrical sources and fMRI activation is important for a plausible neuroanatomic interpretation of EEG sources and for understanding the fine time dynamics of neuronal activation showing fMRI and EEG activation.

Methods

Ten healthy right-handed men (22±3.7 years) underwent one EEG and one fMRI experiment on different occasions after giving informed consent. The electrical stimuli (0.2 ms pulse duration) were applied using a non-magnetic needle inserted under the epidermis on the ventral side of the third phalanx of the right index finger. The stimuli were applied in blocks of 48- second duration with 2-second inter-stimulus intervals. Four blocks of rest and activation of equal duration alternated. In two rounds innocuous stimuli were applied and in two rounds painful stimuli (20% above pain threshold). For the purpose of the present study, only results related to painful stimulation are reported.

EEG was recorded using 88 closely spaced Ag/AgCl electrodes (sampling rate 1024 Hz, bandpass filter 0.015-200 Hz) using BrainScope system (M&I, Prague, Czech Republic). The 3-D positions of the EEG electrodes were measured using Isotrak II system (Polhemus Navigation USA). The functional MR imaging was performed on a Siemens Vision 1.5T using a single-shot gradient-echo EPI sequence (TR=6 s, TE=54 ms, flip angle = 90°) in 29 slices with 4 mm thickness. The FOV of 230 mm and the matrix size of 128^2 yielded an in-plane resolution of 1.8 mm^2. High-resolution anatomical images of the whole head were acquired using FLASH sequence (TR=25ms, TE=6ms, flip angle=20°, slab of 180 mm and 180 sagittal partitions, FOV=256 mm and matrix size=256^2). EEG data were analyzed in 0.75 s epochs with 0.25 s preceding and 0.5 s following a stimulus onset. All artefact-free epochs were averaged and bandpass-filtered (1-40 Hz) and analyzed using the Brain Electrical Source Analysis program (Megis GmbH, Munich, Germany). The source model was constructed individually using a four-shell ellipsoidal head model regarding the global field power and residual variance of EEG waverforms indicating unexplained variance.

Using BrainVoyager 4.4. (BrainInnovation), the functional data were coregistered to the first image and motion artifacts were corrected. The images were smoothed in time and space and coregistered to the high-resolution anatomical images. The activation maps were obtained by correlating the signal intensity with the box-car function. This model function was delayed by 6 seconds to account for hemodynamic response. Clusters counting at least 100 contiguous voxels and exceeding the correlation level of r=0.4 were accepted as significant.

Using two preauricular points and nasion as fiducials, the electrode array was matched to the segmented head surface with an average error of 1-2 mm. The x,y and z coordinates of cluster maxima of fMRI activation and the 3-D origins of EEG sources projected onto the functional and anatomical images were measured.

Results

Fig. 1 shows the pain-related functional activation and EEG sources in transversal, coronal and sagittal projections in one subject. In nine subjects, a good correspondence between fMRI clusters and EEG sources were observed in the contralateral parietal operculum (SII and insula) and in the mesial frontal cortex (SMA and cingulate cortex). The mean distances between EEG and fMRI clusters for the contralateral SII and for the mesial frontal cortex (SMA) are shown in Tab. 1.

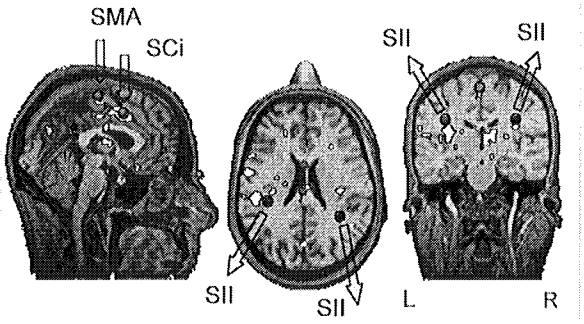

Fig. 1 3-D projections of pain-related fMRI activation (white spots) and EEG sources (circles) in one subject. SCi = cingulate sulcus. L=left, R=right.

	x	y	z
Contralateral SII [mm]	1.3±2.5	2.1±2.0	14.6±7.1
SMA [mm]	4.2±2.6	2.6±2.0	7.3±4.5

Tab. 1 Absolute x,y and z distances (mean ± SEM) betwen fMRI cluster maxima and EEG sources in contralateral SII and mesial frontal cortex.

Discussion

The results suggest that repeated painful stimulation induced hemodynamic and electrical responses at similar locations in the contralateral parietal operculum and in the mesial frontal cortex. Our findings are in line with recently reported correlations between BOLD-signal changes and local field potentials in the visual cortex in monkeys [7]. The distances between the fMRI cluster maxima and source locations, especially in the inferior-superior axis, can be attributed to the spherical head model used in EEG source localization, which gives an error up to 10 mm [8]. However, we also found cortical regions lacking an EEG source in the presence of fMRI activation, suggesting that EEG source localization and fMRI also provide complementary information about cortical processing during repeated painful stimulation.

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