MEG & fMRI: Which one best spatially localizes brain activity?

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Background: Functional MRI (fMRI) and magnetoencephalography (MEG) have been identified as potentially useful tools for pre-surgical mapping. In this context, the neuroimaging tools must demonstrate a high degree of spatial specificity, and produce robust and reliable activation patterns. We aim to compare the efficacy of a simple motor task for localizing the primary motor cortex in both fMRI and MEG experiments. We will use a number of measures of activation strength and localization accuracy. This work is part of a larger research program comparing fMRI and MEG in both patients and healthy controls, in the context of presurgical mapping of both language and motor functions. In this abstract we present preliminary results of this research program.

Methods: 15 healthy volunteers will perform functional brain scans on both a 4 T MRI (Varian) and a 306 channel MEG system (Elekta). Each participant will complete the motor task four times at each session. The task consists of bimanual palmar flexion (grip-movement), prompted by a leftward (<) or rightward pointing arrow (>) presented for 500 ms. The task uses a combined block/event design (40 s task/20 s rest blocks, 1.5-4.5 s ISI, 4 blocks, 80 stimuli total, 4:00 duration).

Functional MR imaging used a spiral out trajectory (TR=2 s, TE=15 ms, α=90°, 64 x 64 matrix, 25 slices, and 3.75 x 3.75 x 4 mm voxels, 0.5 mm gap). Functional MRI images were analyzed with FSL. The fMRI data were motion corrected, high-pass filtered (0.01 Hz), spatially smoothed (FWHM 5mm), and pre-whitened. The regressors for the linear model were created by convolving a double-gamma response function with 500ms duration, unit-amplitude stimulus impulses. Separate stimulus regressors were created for the left and right hand (l.h. and r.h. respectively). T-statistic images were formed for four combinations of regressors (l.h.>rest, r.h.>rest, l.h.&r.h.>rest, l.h.>r.h.).

MEG data was collected at 1000 Hz, and down-sampled to 250 Hz prior to analysis. MEG data was analyzed using Brainstorm. A realistic head model was produced by segmentation and tessellation of a T1 MRI collected in the same MR session as the fMRI data (MP-FLASH, 1x1x3 mm resolution: up-sampled to 1mm^3 resolution). MEG evoked responses were created by band-pass filtering (0.1-75 Hz) and parsing the data relative to the left and right button presses (pre-response period of 1s, post-response period of 0.5s). A volume minimum norm (MNE) approach was used to estimate the MEG source magnitude at each location on the fMRI grid for every time-point in the evoked response. Pseudo-t statistic maps were produced by dividing the MNE source magnitude at each voxel (averaged over +/-20 ms around the button press) by the deviation of the baseline period activity. Thus two images (l.h.>rest & r.h.>rest) were produced from each of the four MEG runs.

Four replications of each of the six functional maps (4 fMRI contrasts and 2 fMRI contrasts) were produced from the four separate scans. The activation within a sensorimotor ROI consisting of Brodmann's areas 1, 2, 3, 4, 5, 6 and 43 was investigated for each replication. Mean values of the peak magnitude, and activation extent within the ROI were evaluated to assess the activity within the presumed motor cortices. Reproducibility of this activity was calculated using the Rombouts overlap coefficient [1]. Laterality Indices (LI=[V_{LEFT}-V_{RIGHT}]/[V_{LEFT}+V_{RIGHT}]), and the fraction of all the activated voxels (V_{TOTAL}) that are within the sensorimotor ROI (V_{ROI}) were also calculated. A threshold of $p<0.0005$ was used for all calculations.

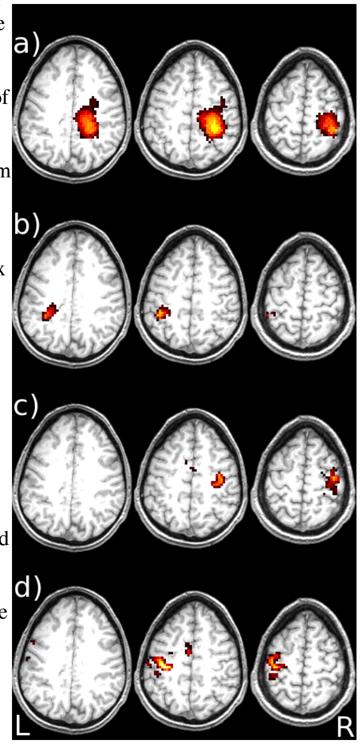

Figure 1: MEG activation maps (a,b) and fMRI activation map (c,d) the left hand > rest (a,c) and right hand > rest (b,d) conditions (p<0.0005).

Results: Preliminary results indicate that the l.h.>r.h. contrast produces the fewest active voxels of the four fMRI contrasts tested, however it had the highest value of V_{ROI}/V_{TOTAL}, and therefore the most specific to the sensorimotor ROIs (table 1). This contrast had the lowest laterality index, but this calculation did not consider the polarity of the left and right hemisphere activations (in this contrast on hemisphere produces negative t-statistic values). This map can thus be split into positive and negative activity, each of which was completely lateralized in this subject (not shown). The greatest fMRI sensitivity was for the l.h.>rest and r.h.>rest contrasts. These were also provided the most reliable localization, as measured by test-retest overlap.

In the MEG images, the left button press produced significantly higher activation magnitude, and thus greater activation extent than the right button press (figure 1). These maps were completely lateralized at the significance threshold chosen. The majority of the activated voxels for MEG were outside of the motor ROI, although most of these were in neighbouring regions deep to the sensorimotor ROI, and contiguous with the sensorimotor cortex activation (figure 1). The epicentre of the MEG activity for both hands localized to the post-central gyrus. The test-retest overlap for the MEG images were on par with the best results observed for fMRI.

Discussion & Conclusion:

*Table 1: Summary of motor task activation properties (*p<0.0005). MEG data was averaged from -20 to +20 ms relative to the left and right button presses. Abbreviations: l.h. = left hand, r.h. = right hand, V_{ROI} = active volume in ROI V_{TOTAL}=active volume in whole brain.*

	Modality	fMRI				MEG	
Hemisphere	Contrast	l.h. > rest	r.h. > rest	l.h.&r.h. > rest	l.h. > r.h.	l.h. > rest	r.h. > rest
Left	Peak magnitude	5.34 ± 0.54	11.3 ± 2.2	8.85 ± 1.61	6.69 ± 1.59	3.49 ± 0.29	6.09 ± 0.72
	Extent (voxels)*	49 ± 42	518 ± 201	511 ± 239	159 ± 64	0 ± 0	75 ± 23
	Retest overlap*	0.31 ± 0.15	0.63 ± 0.09	0.58 ± 0.11	0.66 ± 0.11	0.0 ± 0.0	0.54 ± 0.08
Right	Peak magnitude	9.54 ± 1.33	4.18 ± 1.10	7.69 ± 1.23	7.41 ± 1.40	8.38 ± 1.18	3.01 ± 0.69
	Extent (voxels)*	268 ± 60	15 ± 16	235 ± 152	116 ± 74	567 ± 212	0 ± 0
	Retest overlap*	0.68 ± 0.03	0.0 ± 0.0	0.32 ± 0.07	0.46 ± 0.24	0.67 ± 0.13	0.0 ± 0.0
Both	Laterality*	-0.70 ± 0.23	0.96 ± 0.04	0.44 ± 0.18	0.21 ± 0.45	-1.0 ± 0.0	1.0 ± 0.0
	V_{ROI}/V_{TOTAL}*	0.64 ± 0.18	0.58 ± 0.19	0.49 ± 0.14	0.80 ± 0.16	0.36 ± 0.09	0.24 ± 0.09

It is unclear at this time why the MEG activation was more extensive for the left hand movements than the right, and whether this behaviour will be observed at the group level. At higher activation thresholds the right hemisphere MEG activity is localized similarly to the left hemisphere activity. However, in either case the MEG results localize to the post-central sulcus, and likely represent a movement-evoked field [2]. It thus appears that fMRI demonstrates greater spatial specificity to the presumed primary motor cortex. The fMRI activity was maximal in the pre-central gyrus, and followed the sulcal geometry closely. While we expect to demonstrate a pre-central gyrus response at an earlier latency (t ~ -40 ms) [2], the strongest response observed was that shown. Additionally, it is unlikely that the MEG activity at any latency will follow the sulcal geometry in the absence of explicit anatomical constraints. As functional neuroimaging becomes increasingly popular for presurgical mapping, advances in spatial precision are of critical importance. **References:** [1] Rombouts et al., AJNR: 18, 1317-1322 (1997). [2] Cheyne et al., HBM 27, 213-229 (2006).