Combining MEG and fMRI for Single-pass MEG Analysis – A Simulation Study

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In magnetoencephalography (MEG), a helmet containing a large array of highly sensitive superconducting quantum interference device (SQUID) sensors is used to measure the weak magnetic fields arising from human brain activity. In a typical MEG sensory response experiment, a single MEG pass measures the brain activity corresponding to a single application of a stimulus, such as the sounding of a tone. Usually, 100 or more passes are recorded for a given stimulus, and their average is used to perform location and timecourse analysis of the stimulus-induced brain activity. Inferring locations and timecourses of brain activity from MEG measurements, the MEG inverse problem, is a hard problem to solve, and has been addressed with a wide array of approaches. A subset of these are dipole model approaches that assume the sources of activity are point-currents (dipoles). One approach developed at LANL is the Calibrated-Start Spatio-Temporal (CSST) Dipole Model. In CSST, the number of regions of brain activity is first estimated, then nonlinear simplex searches are applied to multiple sets of starting locations to find the set of dipoles and their associated timecourses that best account for the measured data. Because of the low signal-to-noise ratio, inverse analysis of single-pass MEG data is hard, or impossible. In some cases, using information from other sources could aid in this analysis.

In functional magnetic resonance imaging (fMRI), a magnetic resonance imaging (MRI) scanner is used to detect changes in blood properties, such as oxygenation, to find locations of increased brain activity. One standard approach uses a statistical analysis of the blood oxygenation level dependent (BOLD) response, generating a T-statistic for each voxel in the fMRI volume that provides a measure of brain activity. The fMRI data in a combined MEG-fMRI experiment can complement the MEG data, in terms of providing additional brain activity location information, but does not provide useful information on activity timecourses.

The MEG Forward Simulator in MRIVIEW software was used to create three regions of brain activity, with activity timecourses similar to those shown in the upper right plot in Fig. 1, and MEG sensor timecourses shown in the two left plots. The upper left plot shows noise-free sensor timecourses; the lower left plot shows the same timecourses with added simulated noise, giving a noise level typical of single-pass MEG data.

A simulated fMRI volume was generated by applying a smoothing algorithm to the voxels of the three simulated regions, to create brain activity maps similar to those obtained in an fMRI analysis. A probability volume was obtained for these regions by scaling the voxel values in the smoothed volume to the interval [0,1]. This volume was registered to the MEG coordinate space. During the CSST search process, the voxel values of the probability volume were used to weight the MEG-only Chi-square measure for a given set of locations, to produce a combined (simulated) MEG-fMRI measure.

The lower-right plots in Fig. 1 show the benefits that may be realized with a combined MEG-fMRI analysis. The combined MEG-fMRI analysis demonstrates the fMRI influence on dipole locations. In the combined analysis, the fitted dipole locations are pulled toward regions of high fMRI activity, counteracting the influence of the MEG noise on the dipole fits. The dipole timecourses arising from the combined CSST analysis of the noisy simulated MEG data more closely match the low-noise analysis results, as evidenced by the shape and peak amplitudes shown in green and blue. In the MEG-only case, the peak green dipole timecourse amplitude is 50% higher than it should be, because of complications in dipole fitting arising from the sensor noise. A similar problem can be seen with the blue dipole. For both the green and blue dipoles, the combined analysis timecourse results closely match the actual timecourses. This improvement in timecourse matching most likely arises from the fMRI contribution reducing the error in fitted dipole locations due to the influence of sensor noise.

This probability volume approach to combined MEG-fMRI analysis has also been adapted for use in a Bayesian MEG-fMRI analysis. Probability volumes can be constructed from other types of data, such as structural MRI, positron emission tomography, or MEG analysis results obtained from averaged (low-noise) MEG data.

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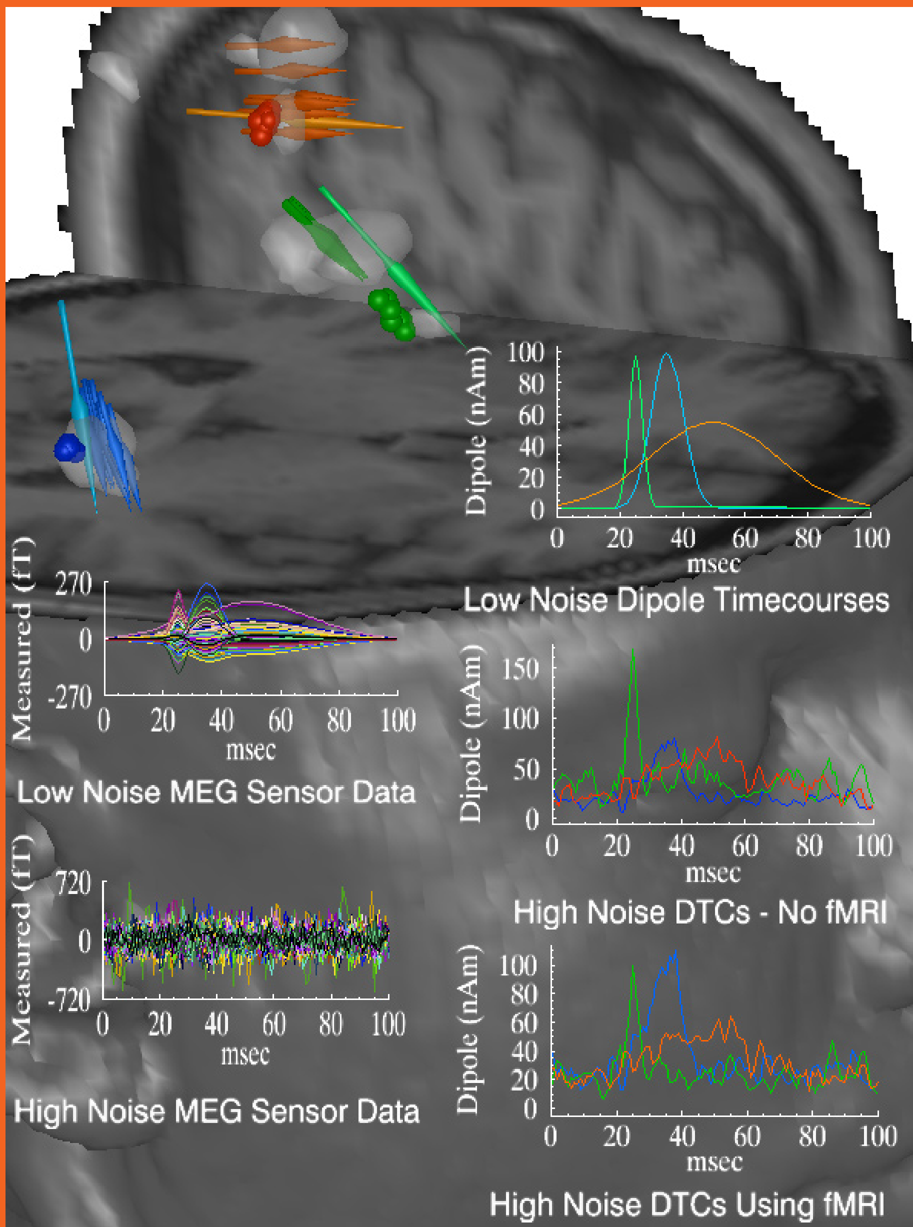

Fig. 1. The MRI head data shown in 3D was used to create simulated regions of brain activity. The white regions represent simulated fMRI data. The 3-dipole CSST solution for the low-noise case is shown with the larger arrows. For the high-noise analyses, the MEG-only solution locations are shown using spheres. The combined MEG, fMRI solution locations are shown using the smaller arrows.