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EEG and MEG Source Analysis of Somatosensory Evoked Responses to Mechanical Stimulation of the Fingers

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Introduction

Previous MEG and EEG studies have successfully utilized electrical stimulation of the digits in order to study generators of early responses in the human primary somatosensory cortex [1-3]. Natural stimulation of the somatosensory system using vibratory pulses to the tips of the digits has been found to elicit qualitatively different responses in the EEG [4, 5] presumably due to the activation of different neuronal pathways. Similar responses have been observed in the MEG to transient mechanical stimuli producing large responses at latencies of 50 msec, corresponding to the electrical P50 response [6,7]. A more recent study [8] also noted MEG responses at 70 msec latencies in some subjects resembling the N70 component described by Hämäläinen and co-workers [4]. The earlier, P50 response is presumed to reflect activation of primary sensory cortex (S1). A study of mechanically evoked epidural and single unit responses in waking monkeys [5] found that this component was associated with a period of inhibitory input to neurons in areas 3b and 1, whereas the later, slow component (N70) was not associated with activity in S1 and appeared to arise from other cortical areas, such as S2. The magnetically recorded P50 (P50m) appears to be the largest and most consistent MEG event recorded during transient tactile stimulation in humans and its potential application for somatotopic mapping studies [6, 7] warrants further investigation of its neural generation. Moreover, the marked orthogonality of the EEG and MEG topographies of the P50 response makes it an ideal candidate for the comparison and/or combination of EEG and MEG localization methods. The current study compared separate high-density, 32 channel EEG and 143 channel MEG recordings in two subjects using identical stimulation paradigms in order to compare dipole source locations in somatosensory cortex obtained separately for each method. In addition, 3-dimensional MRI was obtained for both subjects in order to constrain source model information as well as aid in the integration of coordinate systems for the MEG and EEG source models.

Methods

EEG recordings were made during mechanical stimulation of the finger tips of the right hand in two subjects using a high-density 32 channel EEG system (NeuroScan, Herndon, VA) consisting of a 19 channel grid overlying the left Rolandic fissure and 13 distributed 10-20 locations. MEG recordings were obtained separately using a whole cortex MEG system (CTF Systems, Inc) consisting of 143 1st-order gradiometers covering the whole head. Recordings were performed without magnetic shielding with the aid of software 3rd-order gradient formation with an overall white noise level of about 6 $fT/(Hz^{0.5})$ [9]. Stimuli consisted of 5 msec duration pulses produced by an electromechanical stimulator with an inter-stimulus interval of 750 msec. Acoustic artifacts from the stimulator were masked with white noise and for MEG recordings, the electromechanical stimulator was driven from a distance of several meters to reduce magnetic artifact which was noticeable in some posterior channels. Trials of 256 msec duration were averaged using a 64 msec pre-stimulus baseline and off-line bandpass filtered between 1 and 100 Hz. For EEG data two blocks of 800 trials (1000 samples/sec) were collected and for MEG one block of 600 trials (1250 samples/sec). Comparison of responses for the first and second blocks of EEG data indicated good replicability and dipole fits were performed on the first block of data for comparison with the MEG. For both subjects, three-dimensional proton density magnetic resonance images were obtained with vitamin E markers placed at fiduciary landmarks used to create the head-based MEG coordinate system and selected 10-20 locations. An off-line procedure allowed the identification of these markers in the MRI for the co-registration of the MRI and MEG coordinate systems.

Results

MEG responses showed a clear field reversal peaking at 50-60 msec and a slower component peaking at latencies of 70-90 msec, similar to the P50m and N70m responses observed previously [7]. The P50 component was characterised by orthogonal dipolar patterns of magnetic flux and electrical potential at similar latencies, suggestive of a tangential dipole source with opposite orientation of intracellular and extracellular current measured by MEG and EEG, respectively (Fig. 1). The EEG also showed monopolar distributions of peak responses at latencies of 60 - 70 msec in some conditions, indicative of radially oriented sources not observed in the MEG.

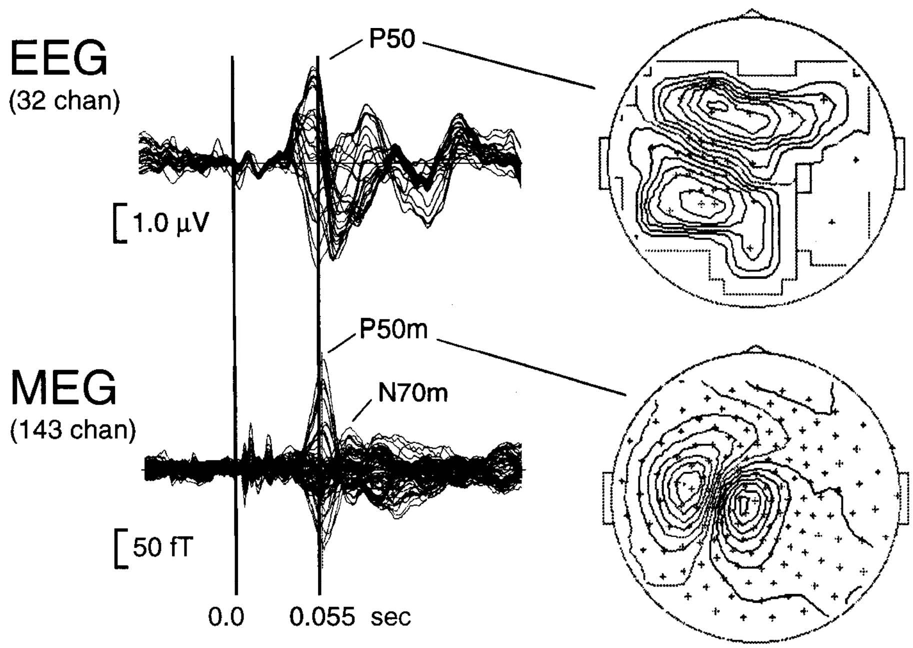

Fig. 1. Left: Superposition of 32 EEG channels (upper) and 143 MEG channels (lower) for averaged response to mechanical stimulation of the right index finger in one subject. Right: Isocontour maps of the electrical and magnetic field patterns at the peak of the P50 response. Small crosses indicate gradiometer/electrode location and darker contours represent outgoing flux and positive potential in steps of 23 fT and 0.37 μV, respectively. Small deflections visible in early phase of MEG response are due to electromechanical stimulator artifact.

Localization of single dipole sources was obtained for the MEG using a least-squares fitting algorithm with corrections for non-radial field contributions [91. A best fit sphere was chosen for each subject based on the structural MRI data, aided by the MRI markers of fiduciary and 10-20 locations. EEG source analysis was achieved using a 4-shell spherical model after Stok [10], based on digitized locations of the electrode montage projected onto a sphere with the same radius. For comparison with MEG results, EEG dipole locations in the spherical model were transformed to a common head-based coordinate system by appropriate translation by the MEG sphere origin (no rotation was assumed). The overall approach for the integration of these three modalities is summarized in Figure 2. Since MEG source localization, which includes non-radial measurements (due to helmet geometry), is dependent on the sphere origin (i.e. definition of radial direction) confirmation of the choice of best-fit sphere was attempted by a trial and error procedure, comparing changes in residual error with slight deviations in the sphere location (indicated by "adjust X,Y,Z" step in Fig. 2). Most interestingly, we found that when the sphere origin was iteratively adjusted in this manner, the initial sphere location based on the MRI produced the lowest error in almost all cases and was therefore accepted as the default origin in subsequent analysis. The sphere origin also determines the location of the EEG sources relative to the MEG sources, since EEG source modelling was performed relative to a sphere with the same radius onto which digitized locations of the electrodes had been projected. Appropriate translation of the EEG source locations by this origin, therefore allows direct comparison of EEG and MEG source locations. As also indicated by Fig. 2, when comparing final source locations based on the two modalities, MEG sources are assumed to provide more accurate information regarding dipole moment (for cases where radial contributions are negligible) and might therefore be used to adjust the EEG spherical model conductivity values.

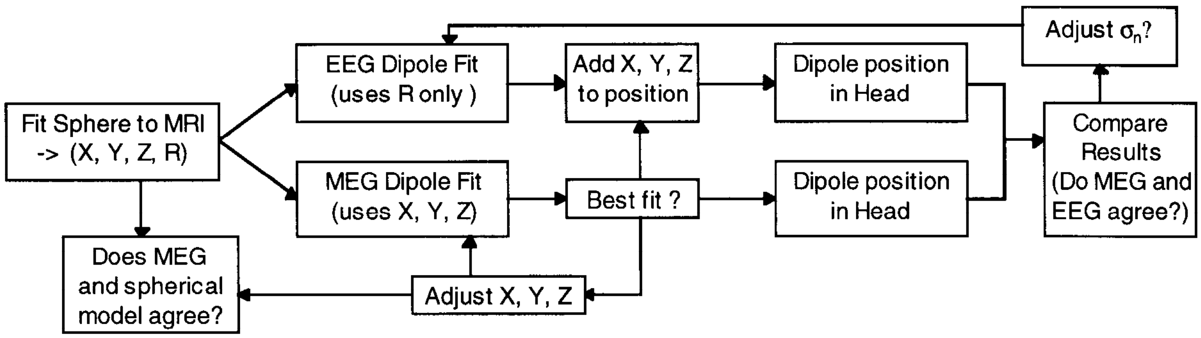

Fig. 2. Flow chart of iterative steps used in the integration of EEG and MEG source modelling procedures with 3-dimensional MRI data. X, Y, Z = sphere location in head coordinate system. R = sphere radius. σ_n= conductivity for spherical model (shells 1.. n).

Tangential dipole sources were localized from MEG data for the peak of the P50m component with residual errors ranging from 2.1% to 6.1%. EEG source localization yielded fits of sources for the P50 with errors ranging from 1.5% to 5.5%. Comparisons of EEG locations to those obtained with MEG were made in the common coordinate system after translation by the sphere origin as described above. Table 1 shows dipole locations obtained for three digits (1 = thumb, 3 = middle, 5 = pinky) for both subjects from EEG and MEG data and the resulting differences in source location and strength indicating generally good agreement between source locations for the P50 component. One notable difference was the degree of lateral dispersion of the sources, which tended to be greater for EEG fits. Additionally, there are some indications of systematic vertical and lateral shifts between EEG and MEG sources in subject 1. Other differences did not show any systematic trend and therefore do not likely reflect incorrect specification of the sphere origin. Constraining the EEG dipoles to a tangential orientation resulted in only minor changes in location and error, indicating that this component is generated by a largely tangential source in S1, most likely area 3b. Dipole moment for EEG fits tended to be lower than that of the MEG by approximately 25 to 50%. Since higher moments would be expected for any contributions of a radial source component, this suggests a possible correction to the spherical model conductivities for the EEG based on the MEG dipole moments.

Table 1. Comparison of dipole source parameters for EEG and MEG dipole solutions in 2 subjects.

Subject 1 Digit	Latency (ms)	Position X (cm)	Y (cm)	Z (cm)	Moment (nA-m)	Error (%)	Subject 2 Digit	Latency (ms)	Position X (cm)	Y (cm)	Z (cm)	Moment (nA-m)	Error (%)
(EEG)				(+5.5)			(EEG)		(-0.5)		(+5.2)		
1	59.0	0.52	3.21	9.07	6.3	1.7	1	56.0	0.69	4.52	8.88	13.9	5.5
3	58.0	0.59	3.27	9.39	7.1	2.8	3	54.0	0.02	3.21	9.09	19.1	2.8
5	59.0	0.23	3.16	9.63	6.0	1.5	5	54.0	-0.03	3.13	8.27	17.5	3.0
(MEG)							(MEG)						
1	59.2	0.45	4.12	9.96	10.3	6.1	1	57.6	-0.32	4.06	8.83	17.5	4.5
3	60.0	0.93	3.76	9.84	15.4	4.9	3	57.6	-0.04	3.98	8.84	23.7	2.3
5	61.6	0.91	4.17	10.28	8.9	3.5	5	60.0	-0.09	4.16	9.01	17.5	2.1
Difference	(EEG -	MEG)					Difference	(EEG -	MEG)				
1		0.08	-0.91	-0.89	-4.0		1		1.01	0.46	0.05	-3.6	
3		-0.35	-0.49	-0.45	-8.3		3		0.06	-0.78	0.25	-4.6	
5		-0.68	-1.01	-0.65	-2.9		5		0.06	-1.03	-0.74	0.0	
Mean		-0.32	-0.80	-0.66	-5.0		Mean		0.38	-0.45	-0.15	-2.7	

Fits attempted for the peak of the N70 component in both MEG and EEG data tended to be less consistent and higher in error, possibly due to the lower signal to noise ratio of these responses. These sources also tended to locate lateral and deeper to those for the P50, consistent with an S2 origin, but were not analysed further in the current study. Dipole locations for the P50 projected onto the appropriate MRI slice indicated location in the region of the postcentral gyrus with a tangential orientation (anterior directed for EEG, posterior directed for MEG) consistent with surface negativity at the posterior bank of the central sulcus, due to either deep inhibitory, or superficial excitatory input to neuronal populations in area 3b. Sources for different fingers tended to be distributed along a line in agreement with the known somatotopy of the hand although these differed in their extent for the MEG and EEG solutions. Also, sources tended to move downward and medial in one subject, and in the other subject upward and medial, suggesting differences in gyral folding which was also evident in the individual MR images.

Discussion

Comparisons of early components of electrically evoked MEG and EEG somatosensory responses have suggested that MEG sensitivity to only tangential sources may provide additional constraints for EEG source analysis [3]. In the current study, somatosensory responses to tactile stimulation of the digits indicated that EEG and MEG responses produce highly orthogonal field patterns at latencies of 50 msec, most likely due to tangential generators in S1, with little contribution from radial sources, allowing for direct comparison of dipole modelling results from EEG and MEG data independently. This result is similar to that found by Buchner et al., [3] for the 30 msec (N30/P30) response evoked by electrical stimulation. In addition, we tested strategies for combination of the MEG and EEG coordinate systems, which confirmed structural MRI as a useful tool in estimating the best fit sphere, both for determining contributions of non-radial magnetic fields for MEG dipole solutions, and for the translation of EEG dipole solutions to the MEG coordinate system. This approach yielded similar results for absolute EEG and MEG source locations with overall deviations of about half a centimetre, although some systematic discrepancies remained. Combined solutions for EEG and MEG sources using simultaneously acquired data may provide more accurate source location estimates, although the correct integration of the two coordinate systems will be an important factor for the successful combination of these two methods.

Acknowledgments

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References

[1] Hari, R. and Kaukoranta E. Neuromagnetic studies of somatosensory system: principles and examples. Prog. Neurobiol., 1985, 24: 233-256.

[2] Buchner, H., Adams, L., Miiller, A., Ludwig, I., Knepper, A., Thron, A., Niemann, K. and Scherg, M. Somatotopy of human hand somatosensory cortex revealed by dipole source analysis of early somatosensory evoked potentials and 3D-NMR tomography. Electroenceph. clin. Neurophysiol., 1995, 96: 121-134.

[3] Buchner, H., Fuchs, M., Wischmann, H-A., Dbssel, 0., Ludwig, I., Knepper, A. and Berg., P. Source analysis of median nerve and finger stimulated somatosensory evoked potentials: Multichannel simultaneous recording of electric and magnetic fields combined with 3D-MR tomography. Brain Topog., 1994: 299-3 0

[4] Hämäläinen, H. Kekoni, J., Sams, M., Reinikainen, K. and Nddtdnen R. Human somatosensory evoked potentials to mechanical pulses and vibration: contributions of SI and SH somatosensory cortices to P50 and P100 components. Electroenceph. clin. Neurophysiol., 1990, 75:13-21.

[5] Gardner, E.P., Hdindldinen, H.A., Warren, S., Davis, J. and Young W. Somatosensory evoked potentials (SEPs) and cortical single unit responses elicited by mechanical tactile stimuli in awake monkeys. Electroenceph. Clin. Neurophysiol., 1984, 58: 537-552.

[6] Suk, J., Ribary U., Cappell, J., Yainamoto T. and Llinds R. Anatomical localization revealed by MEG recordings of the human somatosensory system. Electroenceph. clin. Neurophysiol., 1991, 78:185-196.

[7] Yang, T.T., Gallen C.C., Schwartz, B.J., and Bloom, F.E. Noninvasive somatosensory homunculus mapping in humans by using a large-array biomagnetometer. Proc. Natl. Acad. Sci., 1993, 90: 3098-3102.

[8] Cheyne, D., Weinberg H., Hattori, H., Gordon, R., Vrba, J. and Burbank M. In: N. Tepley and G. L. Barkley (Eds.) Characterisation of human sensorimotor cortex using whole-cortex MEG: implications for clinical use. Proceedings of the North American Biomagnetism Action Group Annual Meeting. Detroit, 1994.

[9] Vrba J., Angus, V., Betts K., Burbank M., Cheung T., Fife A., Haid G., Kubik P., Lee S., McCubbin J., McKay J., McKenzie, Robinson, 8., D., Spear P., Taylor B., Tillotson M., Cheyne D. and Weinberg H. A 143 channel, whole cortex MEG system (these proceedings).

[10] Stok C. J. The inverse problem in EEG and MEG with application to visual evoked responses. Ph.D. Thesis, 1986, Krips Repro Meppel.