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Variability and bias between magnetoencephalography systems in non-invasive localization of the primary somatosensory cortex

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ABSTRACT

Objectives: Magnetoencephalography (MEG) provides functional neuroimaging data for pre-surgical planning in patients with epilepsy or brain tumour. For mapping the primary somatosensory cortex (S1), MEG data are acquired while a patient undergoes median nerve stimulation (MNS) to localize components of the somatosensory evoked field (SEF). In clinical settings, only one MEG imaging session is usually possible due to limited resources. As such, it is important to have an *a priori* estimate of the expected variability in localization. Variability in S1 localization between mapping sessions using the same MEG system has been previously measured as 8 mm. There are different types of MEG systems available with varied hardware and software, and it is not known how using a different MEG system will impact on S1 localization.

Patients and Methods: In our study, healthy participants underwent the MNS procedure with two different MEG systems (Vector View and CTF). We compared the location, amplitude and latency of SEF components between data from each system to quantify variability and bias between MEG systems.

Results: We found 8–11 mm variability in S1 localization between the two MEG systems, and no evidence for a systematic bias in location, amplitude or latency between the two systems.

Conclusion: These findings suggest that S1 localization is not biased by the type of MEG system used, and that differences between the two systems are not a major contributor to variability in localization.

1. Introduction

Pre-surgical mapping with magnetoencephalography (MEG) is a valuable tool for patients who require a surgical intervention to resect the pathological cortex [1–6]. MEG identifies pathological and functional areas by non-invasively recording small changes in the magnetic fields produced by electrical activity in the brain using sensors positioned over the surface of the scalp. Localization of the source of electrical activity is achieved by registering MEG data to magnetic resonance imaging (MRI), and deriving regions of activation on the MRI via source estimation techniques.

One clinical use-case for MEG is median nerve stimulation (MNS) to accurately localize the primary somatosensory cortex (S1) and, by proximity, the central sulcus [7–9]. The stimulation generates a somatosensory evoked field (SEF) that is measured at the MEG sensors. Specifically, magnetic field deflections occurring 20 ms and 35 ms after the electrical stimulation (the so-called N20m and P35m, respectively) are used for the localization of S1. The N20m and P35m are reliably present across individuals and have focal and accurate localization in S1, making them ideal responses to use in pre-surgical functional mapping.

For clinical purposes where only one scan is usually possible due to limited resources, it is important to have an estimate of repeated session variance in localization. These findings provide the surgical team with an important estimate of the variability inherent in the S1 localization provided by MEG. Several studies, with similar sample sizes to the current study, have demonstrated sub-centimetre inter-session variability in S1 localization using the SEF [8,10,11]. For example, we have previously reported on within-subject variability for the P35m peak using the Vector View system (Elekta Neuromag, Helsinki, Finland)

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[11]. Between sessions, we found that the variability in localizing the P35m was 8.3 +/- 3.4 mm (sample size = 13). Importantly, this P35m study compared data from imaging sessions on separate days to capture errors associated with the entire scan procedure. The within-session confidence volume for localization was approximately 2 mm^3. This suggests that within-session effects contribute only marginally to variability in localization [12], and that the variability is mainly due to between-session effects.

Prior work has shown that MEG-based S1 localization can be reproduced to within approximately 8 mm. The current study aims to establish the extent to which surgical teams that receive S1 mapping data from different types of MEG systems can treat these data as directly comparable. Previous studies on variability of S1 localization did not investigate the impact of changing the MEG system on localization. In particular, differences in sensor type mean that MEG systems have different sensitivity profiles to the underlying neuromagnetic signal [13]. Studies that investigate the impact of system on S1 localization of the SEF response are needed to provide assurance that pre-surgical mapping is not biased by the type of MEG device used for data acquisition (e.g., system A generally localizes S1 posterior to system B).

While there are studies that have investigated the impact of system on the SEF response, they offer limited information on the effect of system on localization. Ou et al. [14] showed that the variance in the timing and magnitude of the N20m and P35m were dominated by between-subject effects, with between-session and between-system effects contributing minimally. However, they did not investigate location. Ashrafulla et al. [15] reported that between-run overlap in SEF brain maps was equivalent to between-system overlap, but did not compare the locations of peak activity or use a point-source model. For clinical purposes, the location of peak activity (or a point source model) is usually used for S1 localization [2]. As such, this study provided limited information about the impact of system type on localization of a single location for S1.

The primary objective of this study is to quantify the variability and bias between MEG system types when using a paradigm for pre-surgical localization of S1. We collected MEG data during median nerve stimulation in a single cohort of healthy participants on two types of MEG systems, using a matched protocol for participant preparation and data acquisition. Variability and systematic bias in S1 localization between systems was assessed. We hypothesized that the system type contributes minimally to the variability in S1 localization. Further, we hypothesized that there would be no systematic bias in localization between systems. To the best of the authors knowledge, no prior study has estimated variability and bias in S1 localization between these two system types. Thus, this work provides important insight into the impact that the type of MEG system has on reliability and reproducibility in pre-surgical mapping of S1.

2. Material and methods

2.1. Participants

Twelve healthy volunteers participated in the study (5 females; 28.5 ± 6.4 years). All participants were free of neurological disorders and were screened for MEG and MRI compatibility according to institutional procedure. Each participant provided written informed consent prior to the onset of the study. The research was approved by the research ethics boards at the IWK Health Centre and the Hospital for Sick Children.

The data acquisition, analysis, and source localization described below match the clinical practice guidelines for localization of S1 in patient populations [2,9]. MEG data was collected for each participant on two MEG systems. Participants attended one session at each location, with scans of a single participant occurring no more than 10 days apart. The systems used were (“System 1”) a 306 channel Vector View system located at the IWK Health Centre (Halifax, Nova Scotia, Canada) and (“System 2”) a 151 channel CTF system located at the Hospital for Sick Children (Toronto, Ontario, Canada). Unless otherwise indicated, all methodological steps described below were carried out in the same manner on both systems.

2.2. Data acquisition

Data at both sites were recorded at a sample rate of 2400 Hz with an inline low-pass filter at 600 Hz, except for one participant whose data was recorded at a sample rate of 1200 Hz on System 2. This disparity was unintentional, and due to human error. A T1-weighted MRI with isotropic voxel size of 0.8 mm was also obtained for each participant.

Prior to each MEG scan at each site, head position indicator coils were placed on the participant’s head. At the IWK Health Centre, two coils were placed on the forehead and one behind each ear, with all coils placed as close to the hairline as possible. Prior to the scan, the positions of the four coils were digitized using a Polhemus digitization device (Polhemus Incorporated, Vermont, USA), with respect to three anatomical landmarks: the nasion and the left and right peri-auricular points. At the Hospital for Sick Children, three head position indicator coils were used, and the coils were placed directly on the same anatomical landmarks. The disparity in coil positions between systems occurred due to each system requiring a different number of coils for the data acquisition process. A digital picture was taken of each coil on the head and of each landmark to assist in matching registration to MRI and between sites. At both sites, the coil locations were continuously tracked during the MEG session, so that the position of the anatomical landmarks over time was known.

During MEG data acquisition, percutaneous electrical stimulation (DS7A Constant Current Simulator, Digitimer, England) was applied to the left median nerve of the wrist to generate robust activation of contralateral S1. Each stimulus lasted for a duration of 200 μs. Prior to scanning, the stimulator output was manipulated until a faintly visible twitch of the left median innervated thenar muscle could be observed, and the participant reported a sensory response with each stimulus. Stimuli presentation software (Neurobehavioural Systems Inc., USA) was programmed to activate median nerve stimulation once every 200 ms.

2.3. MRI processing and registration to MEG

A head model for each participant was generated following MRI reconstruction (recon-all v. 1.313.2.6) using the FreeSurfer analysis package [16–29]. MEG data for each system were automatically registered to the head model using the MNE python (v 0.14.1) co-registration graphical user interface [30,31]. The position of the anatomical landmarks on the MRI head model were then manually adjusted to match fiducial registration between the two MEG systems for each participant.

2.4. MEG data analysis

Data acquired using System 1 was pre-processed at the IWK Health Centre using the vendor supplied Maxfilter software to reduce environmental noise and estimate head position (maxfilter v.2.2.15, Elekta Neuromag, Helsinki, Finland). Data acquired using System 2 was pre-processed at the Hospital for Sick Children by applying a third order synthetic gradiometer to reject environmental noise. The remainder of the analysis was completed using the MNE python (v. 0.14.1) analysis package [30,31], with the goal of matching the analysis approach suggested for the clinical setting.

System 2 data was converted to the same file format as data acquired from System 1 (.fif files), such that both datasets would be analysed using the same set of commands. A low-pass filter of 500 Hz was applied to the data, as well as a notch filter at 60 Hz and harmonics to remove power line noise. The data were then parsed into 450 epochs