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Feasibility of clinical Magnetoencephalography (MEG) functional mapping in the presence of dental artefacts

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HIGHLIGHTS

- State-of-the-art MEG signal processing techniques enable the removal of artefacts introduced by orthodontic braces.
- Localisation accuracy of SEF and motor responses is comparable in subjects wearing and not wearing braces.
- MEG can be used for pre-surgical evaluation in a much larger clinical population than previously thought possible.

ABSTRACT

Objective: To evaluate the viability of MEG source reconstruction in the presence of large interference due to orthodontic material.

Methods: We recorded the magnetic fields following a simple hand movement and following electrical stimulation of the median nerve (somatosensory evoked field –SEF). These two tasks were performed twice, once with and once without artificial dental artefacts. Temporal Signal Space Separation (tSSS) was applied to spatially filter the data and source reconstruction was performed according to standard procedures for pre-surgical mapping of eloquent cortex, applying dipole fitting to the SEF data and beamforming to the hand movement data.

Results: Comparing the data with braces to the data without braces, the observed distances between the activations following hand movement in the two conditions were on average 6.4 and 4.5 mm for the left and right hand, respectively, whereas the dipole localisation errors for the SEF were 4.1 and 5.4 mm, respectively. Without tSSS it was generally not possible to obtain reliable dipole fit or beamforming results when wearing braces.

Conclusion: We confirm that tSSS is a required and effective pre-processing step for data recorded with the Elekta-MEG system. Moreover, we have shown that even the presence of large interference from orthodontic material does not significantly alter the results from dipole localisation or beamformer analysis, provided the data are spatially filtered by tSSS.

Significance: State-of-the-art signal processing techniques enable the use of MEG for pre-surgical evaluation in a much larger clinical population than previously thought possible.

1. Introduction

Whole-head Magnetoencephalography (MEG) directly and non-invasively measures electromagnetic activity from neurons in the brain. Although MEG requires specialized instrumentation and procedures, it can be used routinely in a clinical setting to record responses from children and adults (Stufflebeam et al., 2009). In particular, MEG has become an important tool for pre-surgical mapping of eloquent cortex in surgical candidates with brain tumours and/or epilepsy (Seo et al., 2011; Pirmoradi et al., 2010), involving typically voluntary movements and somatosensory stimulation. The latest advances in source modelling procedures, such as beamforming, enable the localisation of healthy brain tissue

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involved in, for example, voluntary movement with exquisite temporal (~1 ms) and good spatial resolution (1–20 mm) (Hillebrand and Barnes, 2005). However, a common problem with MEG is the presence of interference due to external sources (e.g. power line interference, cars) and from the participant itself (e.g. heart and muscle interference, orthodontic material) (Vrba, 2002). Modern MEG systems aim to reduce the magnitude of such interferences using a combination of hardware filtering (axial or planar gradiometer configurations) and spatial filtering in software (by forming higher-order gradiometers (Vrba et al., 1999) or signal-only subspaces (Taulu et al., 2004)).

Additional noise rejection can be achieved through signal averaging, or through beamformer based source reconstruction (Cheyne et al., 2007; Adjamian et al., 2009). In a clinical setting, artefacts caused by the presence of metallic orthodontic material, such as braces, can be of such magnitude that it becomes impossible to record an interpretable MEG in some patient groups, like young people, who relatively often wear dental braces nowadays: in our clinical MEG population the incidence of orthodontic appliances was approximately 8% over the last 2 years, which is in general agreement with epidemiological data from the UK (Chestnutt et al., 2006). Fortunately, with recent developments in signal processing, namely the Signal Space Separation (SSS) method with temporal extension (tSSS) (Taulu and Simola, 2006), it is possible to remove even these large artefacts, albeit at the cost of potentially removing true brain signals as well (Medvedovsky et al., 2009). It is therefore important to assess the effect of tSSS on the accuracy of subsequent source reconstructions, particularly when large interference is present. In this study we aim to show that tSSS in combination with beamforming or dipole fitting (using averaged signals) leads to accurate source reconstructions, even in the presence of large interference from orthodontic material. We recorded MEG data during simple voluntary hand movements, as well as following electrical stimulation of the median nerve, both with and without dental artefacts, and used tSSS to spatially filter the data. We subsequently localised the brain regions that were activated during the movement task using beamforming and applied dipole fitting to the SEF data. To the best of our knowledge this is the first systematic study on the effects of dental artefacts on the accuracy of reconstructed neuronal activity and the use of tSSS to improve the localisation accuracy.

2. Materials and methods

2.1. Participants

Six healthy right handed volunteers (4 male, 2 female; mean age: 45 years; age range 33–54) were recruited from staff at the VU University Medical Center (Amsterdam, The Netherlands). Five of the participants did not have dental work that caused discernable artefacts in the MEG. One participant used a brace in daily life. All the participants provided informed consent, and the study was approved by the Medical Ethics Committee of the VU University Medical Center.

2.2. Metallic dental artefacts

Orthodontic braces for the upper and lower dental arches were purpose created by the Academic Centre for Dentistry Amsterdam (ACTA). Each brace was custom made and fit using individual dental casts. The braces were mounted on a plastic base (Supplementary Fig. S1), such that they could easily be put into or taken out of the participant's mouth. In these temporary braces the same amount of stainless steel was used as in normal dental braces.

2.3. MEG recordings

MEG data were recorded in a magnetically shielded room (VacuumSchmelze GmbH, Hanua, Germany) with a 306-channel whole-head neuromagnetometer (Elekta Neuromag Oy, Helsinki, Finland) comprising 102 sensor units, each consisting of two orthogonal planar gradiometers and one magnetometer. The data were sampled at 1250 Hz and an anti-aliasing filter and high-pass filter of 410 Hz and 0.1 Hz were applied, respectively. The electrooculogram was measured from the upper right eye canthi. The head position relative to the MEG sensors was recorded continuously using the signals from four head-localisation coils. The positions of these coils were digitized, as well as the outline of the participants scalp (~500 points), using a 3D digitizer (3Space FastTrack, Polhemus, Colchester, VT, USA). This scalp surface was used for co-registration with the participant's anatomical MRI.

2.4. Anatomical MRIs

Structural Magnetic Resonance Images (MRI) that were available from previous studies, where the axial slice distance varied over subjects from 1.5 to 3 mm, were used. Co-registration of these T1-weighted MRIs with the MEG data was achieved by using surface matching software developed by one of the authors (AH), resulting in an estimated co-registration accuracy of approximately 4 mm (Whalen et al., 2008). A single best fitting sphere was fitted to the outline of the scalp as obtained from the co-registered MRI, which was used as a volume conductor model for the dipole fitting and beamformer analysis described below.

2.5. Stimulus conditions

MEG data were acquired and post-processed according to standard clinical procedures for pre-surgical mapping of eloquent cortex using MEG at the VUmc. The tasks described below were performed once with and once without artificial dental artefacts in a single session. The sequence of the stimulus conditions was randomized across participants.

2.6. Somatosensory task

We recorded MEG responses to left and right median nerve stimulation (SEF) for separate runs by using constant current square wave pulses (2 Hz, 0.2 ms duration, 500 epochs) delivered transcutaneously at the wrist just above motor threshold.

2.7. Motor task

We used a motor paradigm that generates changes in oscillatory activity that can be accurately localised with beamforming. Each run consisted of 15 epochs of 10 s with movement followed by 10 s without movement. The movement consisted of a slow, unilateral, self-paced repetitive non-clenching opening and closing of the hand at about 1 Hz. Movement instructions were presented to the subject using a brief tone (movement) or brief burst of white noise (no movement). Movements were monitored on camera. Left and right hand movements were performed in separate runs.

3. Analysis

3.1. Signal Space Separation

To remove artefacts, the raw data were spatially filtered offline using the temporal extension of Signal Space Separation (tSSS) (Taulu and Simola, 2006; Taulu and Hari, 2009), using MaxFilter