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Impact of different registration methods in MEG source analysis

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Abstract: For this study the impact of different co-registration procedures on MEG source localization of somatosensory evoked fields was evaluated. Two different co-registration procedures were used to calculate the transformation matrix which specifies how to align the MRI data to the MEG head coordinate system. In order to depict the differences, caused by the method, the Euclidian distance between the reconstructed sources was noted. It was shown that, erroneous MRI and MEG data co- registration effects source localization results. Most dipoles are located more posterior and superior when the more advanced registration procedure was applied. In conclusion the results show, that an iterative matching procedure allows an accurate knowledge of the MEG gradiometer sensor position relative to the head which is crucial to correctly reconstruct neuronal activity derived from MEG measurements.

Keywords: co-registration; MEG source localization.

1 Introduction

Reconstruction of brain's activity within the cerebral cortex needs an accurate registration of magnetic resonance imaging (MRI) scans and magnetoencephalography (MEG) records. MEG is a non-invasive technique for recording neuronal activity. In contrast, MRI scans provide detailed pictures of anatomical structures. The registration process describes the spatial localization of the subject's position inside the MEG scanner. For source analysis a volume conductor head model, representing tissue geometries and conductivities, is needed. The realistic single-shell volume conduction model approximates the tissue geometry as one shell of arbitrary (here the individual brain) shape [1].

The MRI scans are usually represented in a coordinate system (voxel space) without physical dimensions and therefore the co-registration is needed to get physical coordinates (source space coordinates) for the voxel. A frequently used technique to achieve an accurate co-registration of the MRI data to the source space relies on three anatomical landmarks (AL). The small number of landmarks which are used for the registration of MEG and MRI data seems to be problematic [2], since errors in landmark determination might lead to large registration inaccuracies. Hence, we decided to digitize points on the scalp surface with a Polhemus digitizer and to perform an iterative matching (IM), which was presented as a more precise alternative [3]. The IM can be performed by the use of the iterative closest point (ICP) algorithm [Besl 1992]. It registers the MRI scans to the MEG data by minimizing the distance between a point cloud and the head surface.

We compared the source reconstruction results of somatosensory evoked responses, obtained by means of the different registration procedures, within a single shell volume conductor head model.

2 Background

In order to take into account brain geometry and volume conduction properties the MEG data need to be registered with the MRI data. Therefore a transformation matrix for the registration of the MRI scan voxel to the source space can be calculated. This is done frequently by the help of three external AL (nasion, left and right pre-auricular points), which are used to define the source space coordinates. Their positions are marked by Gadolinium markers and identified manually within the MRI scans. During the MEG recordings, they are determined by three localization coils. Co-Registration of the data sets (MEG and MRI) means, that the marker positions are used to define the source space. That way, both data sets are represented within the same coordinate system. An accurate co-registration depends on precise determination of

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the AL in both data sets. This registration procedure contains several possible sources of error, since the landmark digitization has an offset of several millimeters [4]. The Gadolinium markers can slip out of place during recordings. Thus their position cannot be accurately defined within the MRI scans. As a consequence, the source space coordinates might differ slightly between MEG and MRI data. Altogether, the small number of landmarks, as well as the sources of error while localization, might lead to an imprecise co-registration of the different data sets.

In order to optimize the co-registration of MEG and MRI data sets, a Polhemus Digitizer is used to record several points of the scalp surface, the region around the eyes and the nose. In this way, registration errors are reduced, since more surface points are used. The ICP algorithm is adapted to the point cloud to fit it with the MRI-segmented scalp surface. The algorithm minimizes the distance between the points of the point cloud and their nearest neighbour on the head surface.

This study determines the differences in source localization with respect to the different co-registration methods. Considering that, somatosensory evoked responses of seven healthy subjects were analyzed using a single shell head model. MEG measurements were made in a magnetically shielded room in supine position (275 channel whole head MEG with 29 reference channels; CTF, VSM, MedTech Ltd.). A square electrical pulse was used to stimulate the median nerve of the patient's wrist. A bandpass filter of 20 250 Hz, a baseline correction and a notch filter (for line noise voltage frequency of 50 Hz and its harmonics) were used to filter the MEG data. The trials were averaged by timelockanalysis after artificial trials and bad channels were excluded from the data.

A single dipole grid search was performed to manage the inverse problem and to find the most probable

Table 1: Sensitivity of MEG source localization with regard to co-registration method for MEG and MRI data: Euclidian differences in dipole location in mm for N 30 components of somatosensory evoked fields in a single shell volume conductor model.

Subject	Dipole A	Dipole B
I	5.07	4.50
II	6.87	6.37
III	10.47	8.02
IV	7.04	4.29
V	14.99	9.43
VI	12.38	12.61

For each subject two sources have been reconstructed. reference: dipole location after IM.

position of MEG measurements. Subsequently, a nonlinear fit was used to optimize the dipole parameter. For all grid points, the squared deviation of the best fitting dipole to the measurement data was calculated to determine the dipole position with a minimal residual variance (RV) and maximal goodness of fit (GOF) value. The GOF is given as $GOF = 1 - RV$ and only those fits with a GOF higher than 0.90 were used for further analyzes. Our results are grounded on the source reconstruction of the somatosensory evoked fields (N 30 components). All processing steps were realized using MATLAB software toolbox FieldTrip.

Figure 1 represents the constructed single shell head models for both registration procedures along with the MEG sensor positions for subject V. It is obvious that the head model is localized more frontal within the sensor cap after the application of the IM.

The Euclidian distances between the dipole locations (in mm) obtained with the different registration procedures are listed in Table 1. The results show that the method of the registration procedure has a distinct

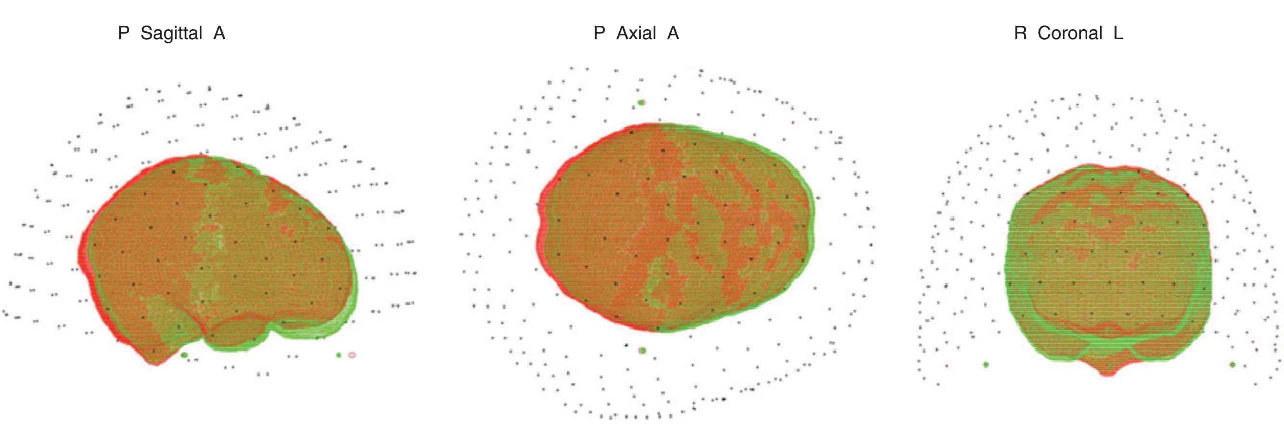

Figure 1: Divergent positions of the single shell volume conductor within the MEG sensor cap (black) caused by different registration methods for MRI and MEG data. Red: head model position obtained after registration based on three AL (landmark positions).

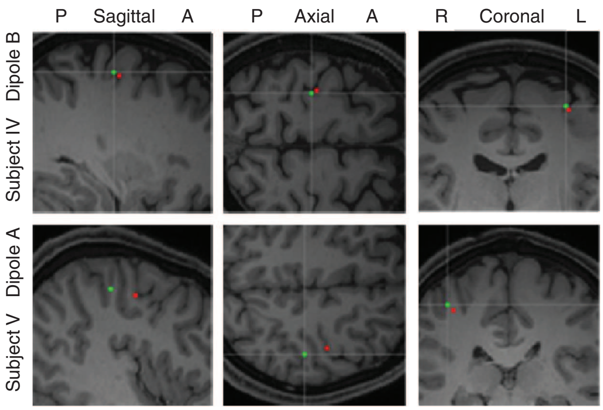

Figure 2: Impact of different MEG/MRI co-registration methods on dipole location for somatosensory evoked fields. The dipole locations for the different registration methods (red: based on three AL and green: IM) are plotted on a T1w-MRI slices. The dipole location based on IM method was used for MRI slice selection and the other dipole was projected on these slices.

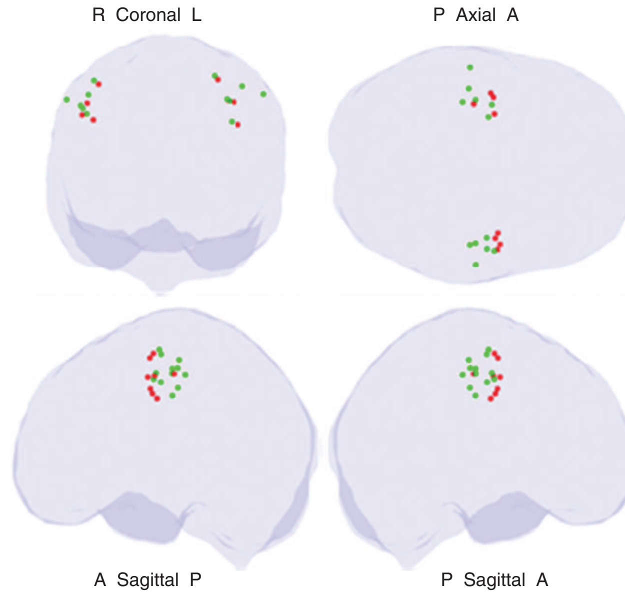

Figure 3: Dipole localizations for all subjects, obtained with the different co-registration procedures (red: based on three AL and green: IM). The IM based dipoles are located more lateral and posterior in most cases.

impact on the source localization. The smallest Euclidian distance amounted to approximately 4.3 mm (subject IV, Dipole B) was detected. The dipole position is visualized in the upper row of Figure 1. The largest distinction was observed for subject V, Dipole A with a value of roughly 15 mm (represented in bottom row of Figure 1). On average the distance between the dipole locations is about 8.76 mm and a value of 8.72 mm is noticeable for the median.

Figure 2 illustrates the dipole positions with the smallest (subject IV, Dipole B) and the largest (subject V, Dipole A) distance with respect to the registration procedure. The red points represent the location obtained after MRI and MEG data were registered with the three AL.

In contrast, the green points mark the location calculated after IM of the MRI-segmented scalp surface and the digitized points of the scalp surface. It is visible, that the dipoles are furthest displaced along the sagittal axis. In addition, slight changes along the frontal and transversal axis are discernible. This becomes visual in Figure 3. The dipoles are obviously located more posterior after the IM registration was applied. This effect was also noticed for most other dipoles. Subject VII seems to be exceptions in this case here a major impact is visible along the coronal axis (changes about 12–14 mm).

3 Conclusion

A precise co-registration MEG and MRI data influences the achievable accuracy in the inverse problem. In that regard, the consequences of different MEG – MRI co-registration methods on source localization of somatosensory evoked potentials were investigated. The co-registration determines the MEG gradiometer sensor positions relative to the head, consequently it has an effect on forward and therefore the inverse solution. On the one hand the MR images were aligned to the MEG head coordinate system using the positions of three AL, on other hand the ICP algorithm was used to calculate a transformation matrix. To examine the effect of the co-registration method on the inverse solution the shift in source localization was calculated. It was shown, that errors in MEG gradiometer sensor localization has a strong impact on the inverse solution. The Euclidian distances between the dipole locations obtained with the different registration procedures were larger than 5 mm in most instances. This means that an inaccurate MEG – MRI co-registration leads to mislocalization of reconstructed sources and should be taken into account when working with somatosensory evoked potentials.

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