MEG to MNI305 and Talairach Space Coregistration

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Abstract

For reporting imaging study results in the rapidly expanding field of neuroimaging research, MNI and Talairach coordinates are the most commonly used basis for specifying locations. Based on these coordinates, atlases of human neuroanatomy and databases of functional neuroimaging studies have been created. For MEG studies, the ambiguity inherit in localization, has motivated research towards combining MEG with fMRI imaging. However, with access to functional imaging databases, multimodal comparisons of MEG with similar fMRI studies are possible, provided the coordinates of the MEG imaging results are in MNI or Talairach coordinates. Also, transformation of individual imaging results to MNI or Talairach coordinates enables subject results to be combined and compared with other studies. We developed a nonlinear MEG to MNI coordinate transformation and have added it to our MEG TOOLS software [6]; available at www.megimaging.com. This transform includes MEG to MRI and MRI to ACPC coregistration after which the cortical volume is extracted by a partially automatic algorithm. Then, a brain surface template based on the MNI305 average brain is matched to the extracted cortex by a volumetric transform that includes linear and locally applied second-order polynomial nonlinear transforms. Generalized Gaussian window functions, whose weights add to one in overlap zones are used to eliminate transform discontinuities. The inverse transform is generated to go from MRI to MNI305 coordinates. The algorithm is rapidly calculated and generates a set of sequentially applied transforms that can be applied to the original MRI pixel coordinates of the imaging results. It is not significantly affected by cortical abnormalities because the initial cortical surface template is not altered to match cortex that is extremely mismatched. The transform from MNI to Talairach coordinates is calculated by a similar transformation and is applied after the MNI transformation.

Introduction

Combining brain imaging results across subjects or comparing imaging results between different studies requires that individual subjects are coregistered to common brain coordinate system such as Talairach or MNI coordinates. These are more than just linear XYZ coordinate systems. Both Talairach and MNI coordinate systems specify the location of brain structure within an AC-PC coordinate system (Fig 1). For Talairach coordinates, the location of brain structure and function (Broddman areas) are based on a single individual. In contrast, MNI coordinates are based on intersubject registration of MR volumetric data of a large number of subjects (MNI-305, ICBM452, ICBM152)[1]. Thus, establishing correspondence of subject MRI voxel locations to MNI or Talairach locations requires the mapping of subject brain structure to corresponding MNI and Talairach brain structure in AC-PC coordinates. A variety of linear and nonlinear transform techniques have been developed to accomplish this task. These techniques attempt to match either subject brain volume structure or brain surface structure to the corresponding MNI or Talairach brain atlas. Three popular registration techniques are AIR [3], FLIRT[4] and included in SPM [5]

The problem with using these MRI/MNI coregistration techniques with MEG imaging results is that they are not part of a unified MEG/MRI imaging application. In addition, MEG imaging primarily involves imaging cortical activity, often in diseased and surgically altered brains. The MRI-to-MNI-to-Talairach transforms we have developed are part of a complete MRI import and processing utility, (available in MEG TOOLS [6]), which are designed to accommodate a wide range of MRI distortion, brain malformations and surgical resections. In addition to the new MNI and Talairach application, the MRI utility now includes: DICOM import, MEG-to-MRI coregistration, MRI-to-ACPC coregistration, and cortical model construction and MEG functional image export in analyze format export matched to MRI, DTI or fMRI imaging results.

Methods 1

- The first step is to create the AC-PC coordinate system using the graphical interface to identify structural landmarks, (Fig. 1).
- Next, the outline of the cortical surface is identified on 5 MRI slices which are interpolated to 15 cortical slice boundaries, (Fig. 2)
- Using linear and locally nonlinear transforms a smooth cortical surface model is fit to the 15 cortical boundaries.
- Within the cortical surface, cortical gray matter is identified and a 4000 source location cortical model constructed for MEG imaging. The cortical surface model of the subject is adjusted to match the outer boundary of the cortical gray matter.
- This cortical surface is transformed to AC-PC coordinates. Then, a combination of linear warps and shears applied to the subject cortical surface to achieve the best match to a cortical surface model of the MNI305 brain. The shears align the anterior and posterior poles of the subject cortical surface with the MNI surface model. A closest neighbor algorithm is used to identify corresponding subject and MNI surface points which are used in all transform calculations. These transforms operate on the volume within the cortical surface as well as the surface.
- Within a sequence of 3 to 5 overlapping Gaussian windows, second order transforms of included brain volume are calculated along the inferior-superior axis (Z) first, left-right axis (X) second, and posterior-anterior (Y) axis last. These locally nonlinear brain volume transforms further optimize the match of the subject cortical surface to the MNI surface model.

$$\text{Window Function} \approx e^{-\left|\frac{5.42(\text{location}-\text{local center})^3}{\text{WindowWidth}}\right|}$$

- A transform matrix **A** is calculated and applied within each window, using the following equation:

$$\begin{bmatrix} X_{MNI} \\ Y_{MNI} \\ Z_{MNI} \end{bmatrix} = \begin{pmatrix} a_{xc} & \cdots & a_{xyz} \\ \vdots & \ddots & \vdots \\ a_{zc} & \cdots & a_{zyz} \end{pmatrix} \begin{bmatrix} C_X \\ C_Y \\ C_Z \\ X \\ Y \\ Z \\ X^2 \\ Y^2 \\ Z^2 \\ XY \\ XZ \\ YZ \end{bmatrix} \quad \text{with } \mathbf{A} = \begin{pmatrix} a_{xc} & \cdots & a_{xyz} \\ \vdots & \ddots & \vdots \\ a_{zc} & \cdots & a_{zyz} \end{pmatrix}$$

Methods 2

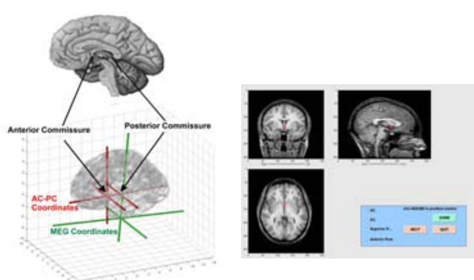

Fig. 1 MEG Tools contains graphical tools for MEG-MRI coregistration and AC-PC coregistration. In this figure, the Anterior Commissure is identified.

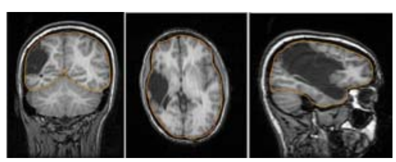

Fig. 2 The location of the cortical boundary is manual identified in 5 slices. This allows the user to compensate for defects, as shown in 3 of the 5 slices for this subject.

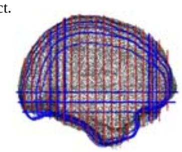

Fig. 3 BLACK: A smooth cortical surface model of the subject is constructed to minimize the surface distance with blue and red cortical boundaries. BLUE: 15 cortical boundaries, 5 are drawn by the user. RED: Outer border of cortical gray matter of cortical source model slices.

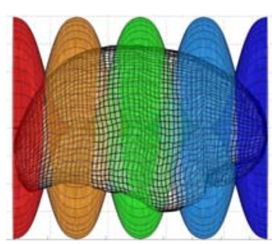

Fig. 4 Five overlapped window functions are shown along the posterior-anterior axis of the cortical surface. The maximum amplitude of each window function is 1. Adjacent window functions overlap and sum of their amplitudes is 1. Thus, the full transform throughout the cortical volume is a continuous mixture of windowed transforms. The same windowing technique is applied along the inferior-superior axis and left-right axis. Further, these one dimensional windows can be altered to be 2 or 3 dimensional windows to achieve more focal sensitivity to mismatch and to accommodate internal structural matching.

Methods 3

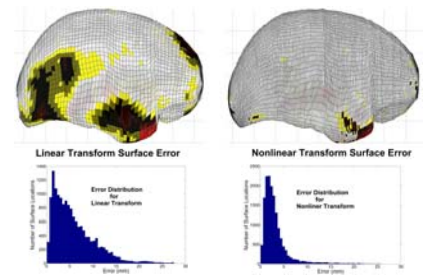

Fig. 5 Errors in transformed cortical surface are shown after the initial linear transformation and after the final nonlinear transformations. The magnitude of the error is displayed in color on the MNI305 cortical surface, (Red corresponding to maximum error). The MNI cortical surface is smooth because averaging a large number of brains, (see Fig. 6)

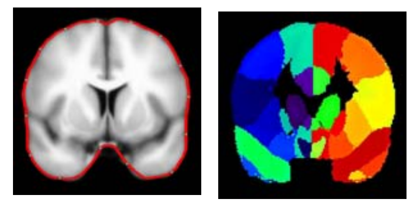

Fig. 6 LEFT: Cortical details of the MNI brain are blurred because it is created from volumetric MRIs normal individuals. Thus the surface (red outline) is smooth (See Fig 4 and 5). RIGHT: MEG Tools included database of anatomical structures [1,2] . Regions of this slice are color coded according to their anatomical identification. Using the MEG Tools solution MRI overlay viewer, a region-of-interest tool can be used to obtain MNI and Talairach coordinates as well as anatomical identification and Brodmann area number for all cortical sites within the region-of-interest.

Conclusions

- A smooth representation of the subject cortical surface is created even for brains with large defects.
- MEG imaged activity is primarily within cortex adjacent to the cortical surface.
- The transformed cortical surface matches the MNI cortical surface within approximately 3 mm. Also, the ACPC coordinate origin of the subject and MNI brain are identical.
- The MEG to MNI Coregistration included in MEG Tools enables the location of all regions-of-interest to be identified in both MNI and Talairach coordinates.
- Anatomical and functional imaging databases can be accessed using MNI and Talairach coordinates1).
- Multiple subject results can be combined after transformation to MNI or Talairach coordinates.

References and Acknowledgement

1. (ICBM), I.C.f.B.M., MNI452 anatomical brain at: http://www.loni.ucla.edu/ICBM/. 2008, International Consortium for Brain Mapping (ICBM).
2. Shattuck D.W., M.M., Adisetiyo V., Hojatkashani C., Salamon G., Narr K.L., Poldrack R.A., Bilder R.M., Toga A.W., Construction of a 3D probabilistic atlas of human cortical structures. NeuroImage, 2008. **39**(3): p. 1064-1080.
3. Woods RP, G.S., Holmes CJ, Cherry SR, Mazziotta JC. , Automated image registration: I. General methods and intrasubject, intramodality validation. . Journal of Computer Assisted Tomography 1998. **22**: p. 139-152.
4. Smith S.M., Jenkinson M., Woolrich M.W., Beckmann C.F., Behrens T.E.J., Johansen-Berg H., Bannister P.R., De Luca M., Drobnjak I., Flitney D.E., Niazy R.K., Saunders J., Vickers J., Zhang Y., De Stefano N., J., Brady M, Matthews P.M., Advances in functional and structural MR image analysis and implementation as FSL. NeuroImage Vol. 23, S1, S208 – S219, 2004.
5. Ashburner J, Friston K.J., Unified segmentation. NeuroImage Vol. 26 No. 3 pp. 839 – 851, 2005
6. Moran J.E., Tepley N., MEG Tools, at: www.megimaging.com

Research supported by NIH/NINDS Grant RO1-NS30914.