Large Deformation Metric Mapping: Increasing Statistical Power in Functional and Structural Maps of the Medial Temporal Lobe

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Introduction

The human brain has significant anatomical variations across individuals. This is one of the central issues in the study of functional magnetic resonance imagery (fMRI). In fMRI studies, it is essential to correctly label the activated regions, while studying the functional properties within the anatomical structures. For this reason, it is necessary to remove the anatomical variations across human brains. Low dimensional transformations focusing on whole-brain alignment such as Talairach techniques are significantly limited in their ability to account for variability, shape and location of brain structures. This study focuses on the use of large deformation diffeomorphic metric mapping (LDDMM) [1] for the alignment of medial temporal lobe (MTL) structures and their functional responses to common extrinsic atlas coordinates. Increasing the dimension of mapping for structure alignment with LDDMM increases the accuracy of data activity localization. Also this technique is general and can be applied throughout the brain.

Methods

The compositional approach outlined in Figure-1 is the basic model for examining functional responses in extrinsic atlas coordinates. In this model, each individual's high-resolution structural (sMRI) image (S) is used to map the corresponding functional MRI (fMRI) image (F) to the common extrinsic atlas coordinate system (A). This can be represented as the FS o SA composite transform.

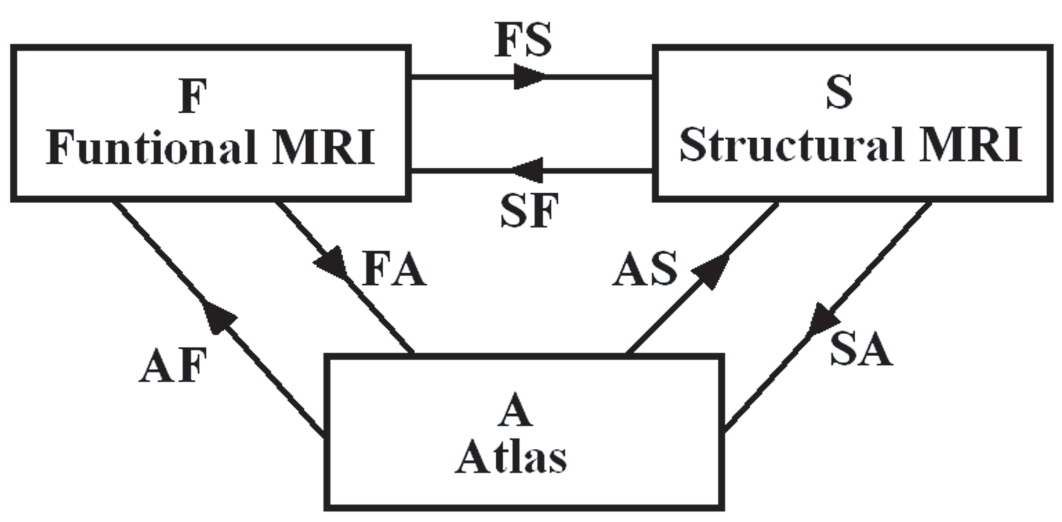

Figure-1

In the construction of the mapping SA or Φ: S→A, there is some observable imagery which drives the correspondence between coordinate systems. Grey valued MRI imagery I(x), x ε Ω is one of the principle observables. The M-ary valued S: Ω → M or "rough hand segmentation" images are another one of these observable imagery. These segmentations are M-labeled masks of structures of MTL such as hippocampus, tempropolar cortex, perirhinal cortex or entorhinal cortex. Figure-2 shows the rough segmentations overlaid on dense images that are gray valued. Red shows the boundaries of rough segmentations for the hippocampus (left panel) and for tempropolar cortex (right panel) The blue shows the gold standard segmentations used for quantifying the accuracy of the mapping algorithms.

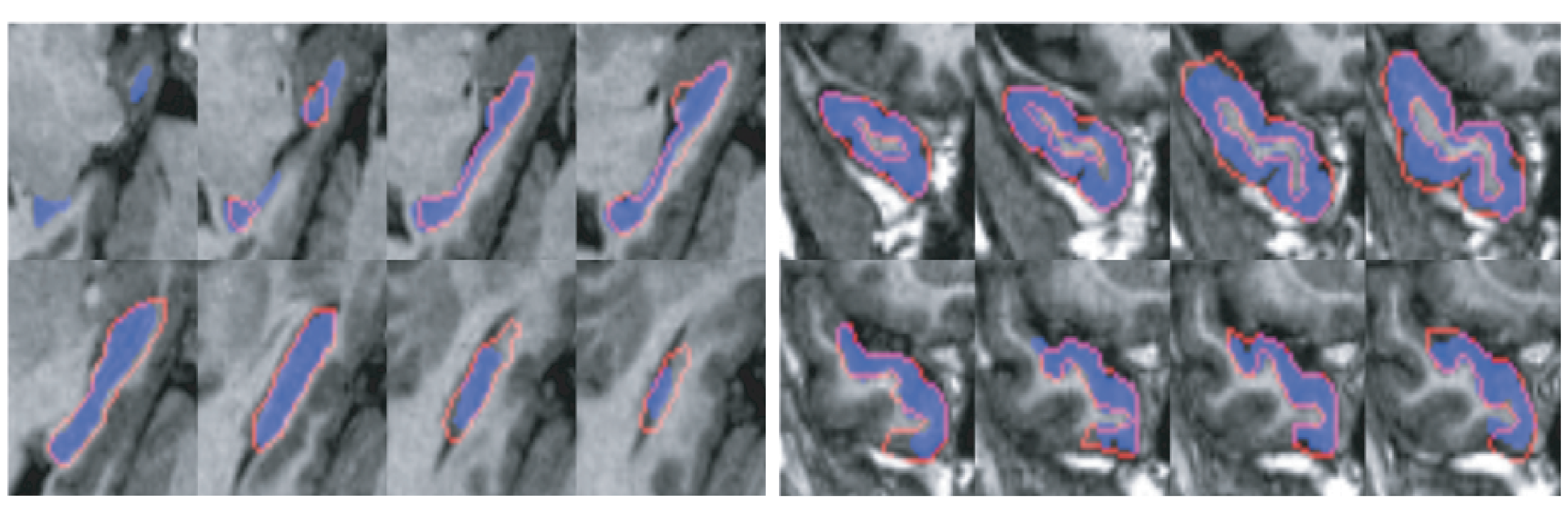

Figure-2

References:

[1] Beg MF, Miller MI, Trouve A, Younes L (2004) Computing Metrics Via Geodesics on Flows of Diffeomorphisms. International Journal of Computer Vision.

[2] Stark C, Okada Y. (2003) Making Memories without Trying: Medial Temporal Lobe Activity Associated to Incidental Formation During Recognition. Journal of Neuroscience

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Metric Mapping Accuracy of Structural ROIs

Figure-3 shows the accuracy of five different mappings applied to the hippocampus (left panel) and tempropolar cortex (right panel) segmentations of nine subjects. For each case the template segmentation is mapped and interpolated onto the target segmentation. For each method, L1 distance (number of the non-overlapping voxels) between the gold-standard segmentation of mapped template image and the target image is calculated. Then the L1-error is calculated by normalizing these distances by the target volume. The error rates are ordered according to the Talairach alignment having the highest error rate. The 12-parameter affine mapping (ROI-AL method of Stark) between the rough segmentations is the next. Then there is the MRI mapping or LDDMM between MRI images, and the LDDMM between the rough segmentations.

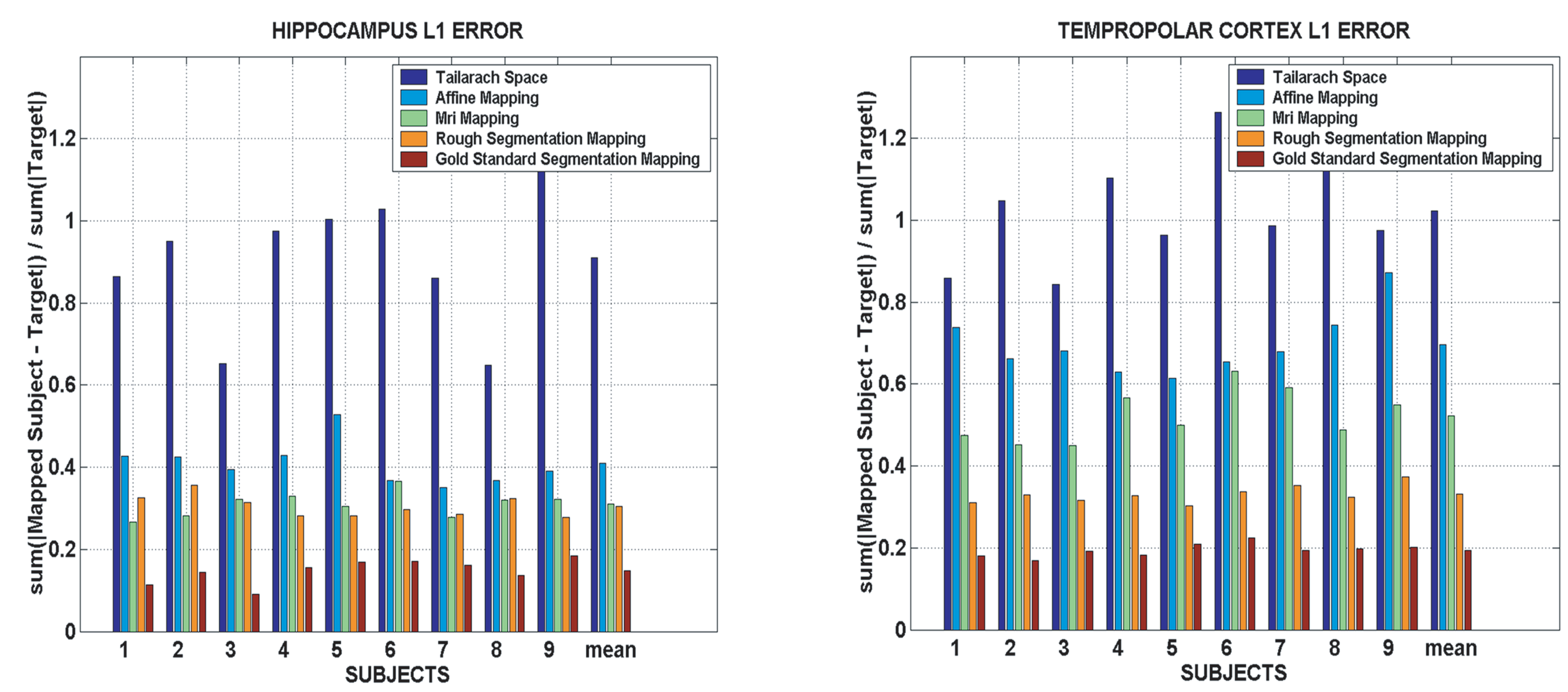

Figure-3

Recruiting Functional Responses of MTL in Extrinsic Coordinates

The structural and functional data in Stark and Okada [2] is used for this experiment. The structural data consists of grayscale MR images of 20 subjects whose fMRI data were recorded during memory tasks. Rough segmentations of MTL structures are used in LDDMM to align the fMRI data of these subjects into common atlas coordinates. The statistical analysis results [2] of this functional data is shown in Figure-4. The left figure shows that the functional data overlap is increased as the methods for registration for functional data is refined from Talairach and Torneaux to ROI-AL and to LDDMM. The improved alignment improves the ability to localize data activity and this assigns functional activity to correct gray matter regions and not to white matter regions. The right figure shows the hemodynamic response from a 39-voxel (609 mm^3) cluster within the right perirhinal cortex following LDDMM transform. The beta coefficient (magnitude of response) represents the general linear model's estimate of the fMRI activity as a function of time. So in LDDMM alignment, in addition to the greater number of significant regions , the activity within the region itself is greater.

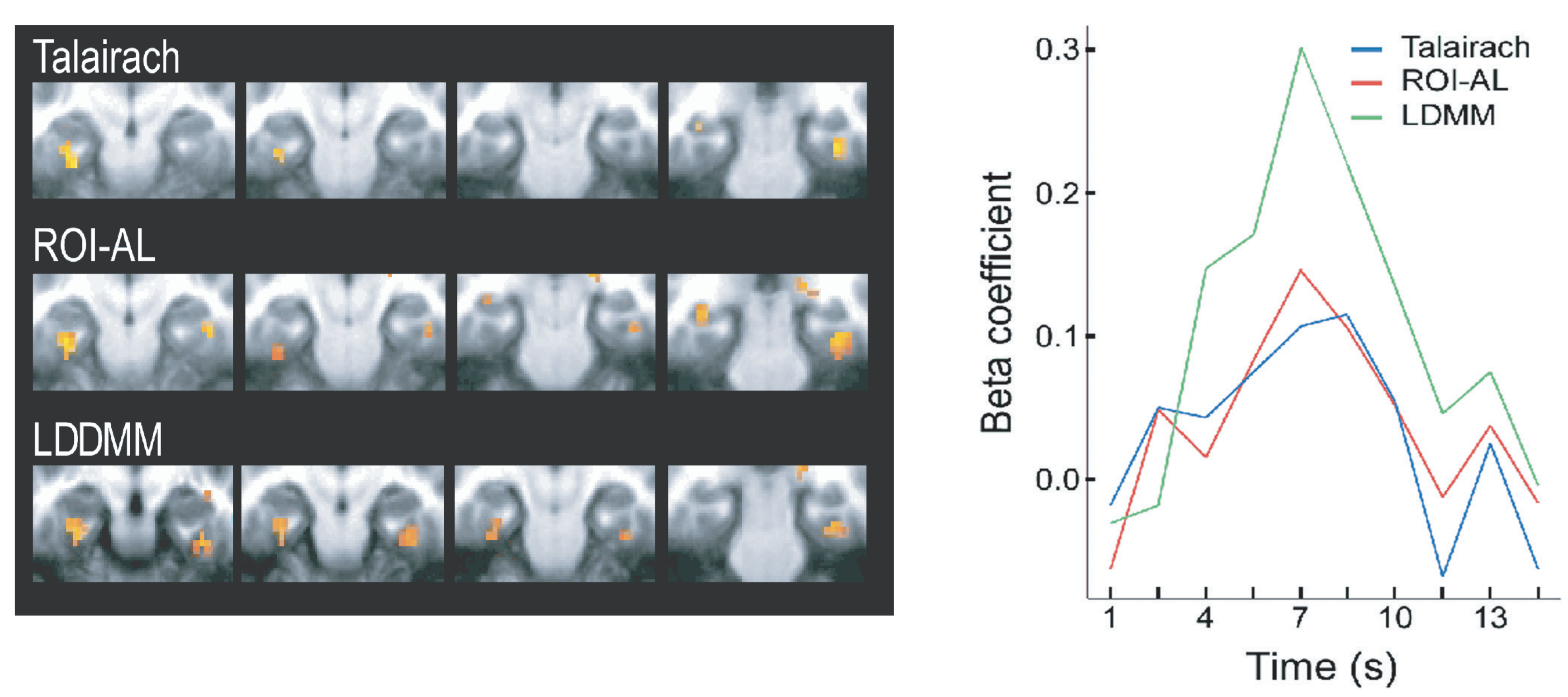

Figure-4

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