Atlas-based online spatial normalization

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Introduction: Automated methods to reduce inter-subject and between-session variability in scan prescriptions are desirable. [1-3] Additionally, atlas-based research has become widely used in neuroimaging. Some challenges for using previously described techniques for atlas-driven applications include the use of rigid-body registration and the use of special-purpose templates meant specifically for online use. Here, fully-automatic alignment of subject anatomy to the popular ICBM452 atlas is integrated with acquisition of a high-resolution 3D anatomical T1-weighted scan.

Methods: Affine normalization to the ICBM atlas is computed during acquisition of high-resolution 3D anatomic imaging. After the low spatial frequencies of k-space have been acquired, a low resolution image is generated and used for normalization. As acquisition of the higher spatial frequencies continues, a brain mask, B_1 nonuniformity correction, and initial 9-parameter affine alignment are computed in parallel. Subsequently, a masked and intensity corrected brain image is produced and used to refine the initial registration using 12-parameter affine registration. The extent of k-space used for online normalization is calibrated to ensure that normalization terminates before the acquisition completes.

Real-time spatial normalization was implemented on a 4 T Varian INOVA whole-body scanner equipped with a quadrature TEM head coil for use with 3D MDEFT imaging (FOV=25.6×25.6×19.2 cm, 256×192×192 matrix, T_{MD}=1.1 s, TR=13 ms, TE=6 ms) routinely acquired for fMRI and MRS studies at our site. The technique was initially developed offline using archived raw data from 79 subjects (age=20±6.2 years, range=12-35; 41♀, 38♂). Subject data was randomly segregated into development (40 subjects) and testing groups (39 subjects) using a stratified random sampling strategy to ensure demographic balance. All development and tuning used the training group data only. The first-pass normalization was implemented using least-squares registration for speed, whereas the second-pass employed mutual information to accommodate contrast differences between the ICBM452 T_1-weighted template and MDEFT imaging at 4 T. Comparable results on training and testing groups indicated good generalization of the technique beyond the training group and real-time performance of the finalized technique was verified online in scans of 10 additional subjects.

Results: The accuracy of online spatial normalization was determined by point-wise comparisons to results obtained from SPM5 nonlinear unified spatial normalization. The disagreement between affine and SPM5 nonlinear normalizations was computed as

$$d(\vec{x}) = \| (A \cdot \vec{x} + \vec{a}) - N_{SPM}(\vec{x}) \| \quad (1)$$

where $\vec{x}$ represents a coordinate inside the brain in the atlas, $(A, \vec{a})$ are the affine registration parameters and $N_{SPM}(\vec{x})$ represents SPM5 nonlinear registration. The distribution of d overall testing subjects is shown in Fig. 1. As a comparison, least-squares optimal affine alignments that minimize $\Sigma\, d(\vec{x})^2$ throughout the atlas were computed for each subject. Median disagreements were 1.9 mm for real-time affine normalization and 1.7 mm for the comparison optimal affine normalizations.

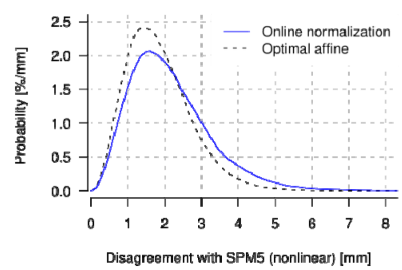

Fig. 1: Normalization accuracy

The testing group included 19 subjects who participated in two imaging sessions. Test-retest reliability was computed by rigid-body registration of subject anatomy between sessions. The inter-session disagreement throughout the atlas was computed as

$$d'(\vec{x}) = \| (R \cdot (A_2 \cdot \vec{x} + \vec{a}_2) + \vec{r}) - (A_1 \cdot \vec{x} + \vec{a}_1) \| \quad (2)$$

where $(R, \vec{r})$ represents the inter-session rigid-body registration; $(A_1, \vec{a}_1)$ and $(A_2, \vec{a}_2)$ represent the affine registration parameters of the first and second sessions, respectively. The distribution of d' is shown in Fig. 2. Median inter-session (test-retest) disagreement was found to be 0.4 mm for the testing group. These results compare favorably with previous results for online inter-session and inter-subject registration.

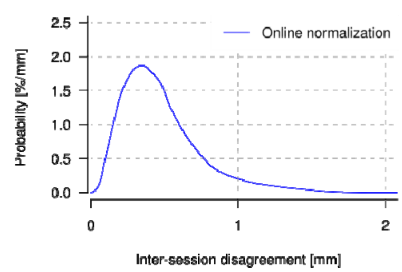

Fig. 2: Test-retest reliability

Discussion: High-resolution anatomical scans are routinely acquired in atlas-based research and use of real-time normalization in these cases will not increase overall session time. Consistent normalization to a widely used atlas is expected to simplify the design and implementation of experimental protocols while improving study-wide consistency of MR prescriptions for group analysis. This is anticipated to improve statistical power for group comparisons, facilitate atlas-based investigations, and support the development of neuroimaging biomarkers and translational research.

References:

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