Optimized nonlinear normalization for voxel-based analyses: A comparison of the Free-Form Deformation in VTK to the Discrete Cosine Function in SPM2

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PURPOSE

Voxel-based analysis (VBA) is a popular tool to identify and illustrate the location of differences between two subject groups. The initial assumption that is required for VBA is that all patients are correctly aligned to a common steriotactic space. This study examined two preprocessing steps and two different normalization algorithms to determine an optimal registration design for a larger study examining therapy related white matter changes in children treated for cancer.

METHODS

T2-weighted (T2w) images from ten patients, four of which demonstrated white matter changes, were selected from a larger study to evaluate the normalization. MR imaging was performed on a 1.5T whole-body system (Siemens Medical Systems, Iselin, NJ). PD- and T2w images (TR/TE1/TE2 = 4470/16/109 ms) were acquired as a portion of a diagnostic scan. Nineteen slices 4mm thick with a 1mm gap covering the cerebrum were collected. For the VBA, an additional patient examination from this patient population was chosen to define an age-appropriate custom template for this patient cohort. The first preprocessing step involved removing the extraminengeal tissues from the T2w images using a threshold controlled region growing technique combined with manual intervention (T2-S). The second preprocessing step utilized more rigorous thresholding of the T2-S image to produce a T2 image with most of the CSF removed (T2-C). These steps were believed to allow for more accurate matching of the brain to brain boundaries necessary in the nonlinear transformations. Two popular normalization algorithms were compared and contrasted. The discrete cosign transformation (DCT) implemented in SPM2 (Wellcome Department of Cognitive Neurology) was compared against the free-form deformation transformation (FFDT) implemented by the CISG group (Computational Imaging Sciences Group) in VTK. Both of these normalization techniques require an affine registration for initialization before computing the non-linear transformation. Transformations were computed using these two algorithms and all 9 combinations of the T2w images as target and source images, and were all applied to the original T2w image of the subject. Normalized Mutual Information (NMI) between the target T2w image and the transformed and resliced T2w image over a range common to all images was used to assess the performance of each preprocessing technique and normalization algorithm.

Table 1 – NMI calculated from the 18 combinations of algorithms and images for 10 subjects.

Target	T2	T2	T2	T2-S	T2-S	T2-S	T2-C	T2-C	T2-C
Source	T2	T2-S	T2-C	T2	T2-S	T2-C	T2	T2-S	T2-C
FFDT1	**1.147**	1.099	1.097	1.120	1.130	1.129	1.117	1.129	1.130
FFDT2	**1.153**	1.106	1.105	1.131	1.149	1.148	1.131	1.145	1.145
FFDT3	**1.154**	1.113	1.112	1.132	1.148	1.147	1.133	1.145	1.147
FFDT4	**1.160**	1.108	1.108	1.120	1.148	1.148	1.120	1.146	1.145
FFDT5	**1.156**	1.113	1.109	1.122	1.146	1.147	1.122	1.145	1.142
FFDT6	**1.163**	1.117	1.118	1.125	1.159	1.157	1.123	1.158	1.156
FFDT7	**1.167**	1.109	1.109	1.131	1.161	1.157	1.130	1.156	1.155
FFDT8	**1.161**	1.110	1.103	1.120	1.153	1.153	1.121	1.153	1.151
FFDT9	**1.157**	1.104	1.103	1.120	1.144	1.147	1.120	1.142	1.142
FFDT10	**1.149**	1.099	1.099	1.131	1.140	1.135	1.131	1.141	1.138
DCT1	**1.128**	1.086	1.083	1.118	1.113	1.116	1.117	1.112	1.120
DCT2	**1.142**	1.097	1.094	1.128	1.136	1.128	1.128	1.135	1.141
DCT3	1.138	1.101	1.099	1.134	1.140	1.140	1.129	1.134	**1.141**
DCT4	**1.145**	1.095	1.095	1.121	1.121	1.120	1.118	1.120	1.120
DCT5	**1.130**	1.094	1.093	1.124	1.126	1.119	1.122	1.125	1.128
DCT6	1.142	1.101	1.098	1.126	**1.148**	1.146	1.123	1.144	1.147
DCT7	1.144	1.100	1.100	1.123	**1.153**	1.143	1.120	1.144	1.152
DCT8	1.133	1.096	1.095	1.121	1.140	1.136	1.120	1.131	**1.145**
DCT9	**1.140**	1.092	1.092	1.118	1.134	1.133	1.117	1.128	1.137
DCT10	**1.136**	1.089	1.085	1.128	1.132	1.126	1.119	1.128	1.134

RESULTS

Normalizations results are shown in Table 1, with the maximum NMI for each subject highlighted in yellow. The T2w image used as the target and source image provides the best results in all subjects using the FFDT algorithm and in six subjects with the DCT algorithm. The FFDT algorithm always provided a higher computed NMI than the DCT algorithm for the same target and source image.

CONCLUSIONS

The results of this study suggest that the additional time and computation used to remove the extrameningeal tissues and the CSF from T2w images does not provide additional accuracy when performing normalization. Improved normalization was observed using the free-form deformation transformation from the CISG group. With this additional accuracy in the normalization of images, the resulting voxel-based analyses can better assess the underlying processes of interest.