Application of Distortion Correction Procedures to Spin-Echo EPI for fMRI Studies in the Temporal Lobe

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Introduction Gradient echo (GE) echo planar imaging (EPI) is the sequence of choice for most fMRI studies due to the rapid acquisition time and high sensitivity to T_2*. Although very successful in detecting haemodynamic responses to activation in the majority of the brain, magnetic susceptibility effects from air-tissue interfaces cause severe problems with geometric distortions and loss of signal from intra-voxel dephasing when GE-EPI is used for studies involving regions in the frontal and temporal lobes. Although less sensitive to haemodynamic activation, spin echo (SE) EPI is a possible alternative to GE-EPI as it is not subject to signal loss through intra-voxel dephasing, and although geometric distortions still occur a number of strategies have been proposed for correcting these distortions. We report here on three novel variants for applying the dual phase-encode traversal technique described in (1 & 2)) to an SE-EPI fMRI acquisition based on a word categorisation task involving semantic understanding, which is known to produce temporal lobe activation (3). In brief, the three correction methods all involve obtaining a pair of images with opposite direction k-space traversal and resultant distortion, co-localising signal from matching 1-D profiles in the phase-encoding direction and repositioning that signal at the mean of the 2 profiles. The novel aspects of the proposed methods lie in both the way the data is acquired and in the application of the correction procedure to minimise TR.

Methods *Data acquisition* All imaging was performed on a 3T Philips Achieva scanner using an 8 element SENSE head coil with a sense factor of 2.5. The SE-EPI fMRI sequence included 30 slices with TE = 75 ms, TR = 3200 ms, 112 × 112 matrix, reconstructed resolution 1.875 mm, and slice thickness 4.2 mm. Two fMRI acquisitions were made on ten subjects, 5 male, 5 female, all right handed, age range 22-45. Acquisition no. 1 consisted of 160 time points with interleaved alternate direction k-space traversal with either right-left or left-right phase-encoding. Acquisition no. 2 consisted of a 20 time point pre-scan with interleaved dual direction phase encoding and the subject at rest, followed by the main fMRI image sequence of 160 time points with a single phase encoding direction over which the fMRI task was performed. Five of the subjects were imaged with acquisition no. 1 first and five with no. 2 first. The fMRI stimulus consisted of a word categorisation task involving presentation of three sequential cue words followed by a fourth underlined target word that required a rapid decision as to whether it belonged to the same category as the cue words. A letter categorization task with subjects presented with three strings of identical letters and a fourth underlined target string on which subjects were required to make a decision was used as a baseline condition. Stimuli were presented in blocks of 8 (4 same, 4 different categories, random order) with 8 blocks each for word and letter categorisation. Each block lasted for 32 s alternating between word and letter blocks. This task has been previously shown to activate areas in the temporal lobe (3). A high resolution GE structural scan was also obtained for an indication of distortion correction accuracy.

Application of distortion correction Acquisition no.1 was corrected using two methods that we will refer to as A and B: A) Each pair of images was corrected following the method in (1), resulting in a series of 80 distortion-corrected images with an effective TR of 6400 ms. B) Maps of the pixel shift required to translate both distorted images of each pair into the corrected space were generated and used to transform both images separately, thereby maintaining a corrected sequence with 160 time points, TR 3200 ms. Acquisition no.2 was corrected by first manually choosing the closest matching image pair (particularly in respect to vascular and CSF pulsation artefacts) from the dual phase-encode 20 image pre-scan and applying the correction method in (1). A map of pixel shift required to correct the images was then calculated. Each image from the fMRI series was then registered to the chosen uncorrected pre-scan image using a 12 parameter affine registration (FLIRT, FSL, Oxford). Distortion in the registered fMRI series was then corrected by application of the pixel shift maps derived from the pre-scans, resulting in corrected fMRI series C with 160 time points, TR 3200 ms. All three distortion corrected datasets were then subjected to statistical analysis using FEAT (FSL, Oxford).

Results and Discussion Significant activation defined by cluster analysis ($p < 0.05$) was detected in all subjects for method C and in 9 subjects for methods A and B. The total number of voxels per individual with a z score more than 2 was significantly higher in B than A (Friedman's anova and Tukey's HSD criterion, $p = 0.05$) although no significant difference was found between B and C (Fig. 1). The number of voxels with $z > 3$ and $z > 4$ was generally higher with methods B and C than with A and significantly higher (Friedman's anova and Tukey's HSD criterion, $p = 0.05$) in the case of B and A with $z > 3$ (Fig. 2) and C and A $z > 4$ (Fig 3).

1

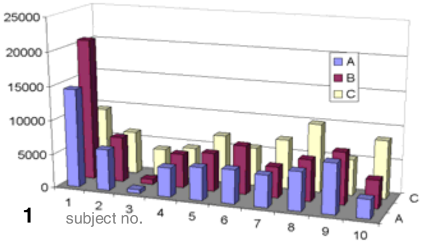

Figure 1 *total no. voxels with z > 2.0*

2

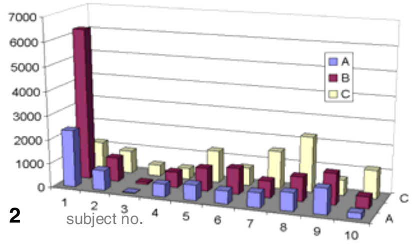

Figure2 *total no. voxels with z > 3.0*

3

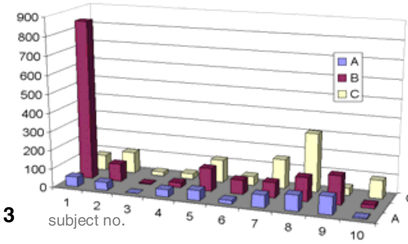

Figure 3 *total no. voxels with z > 4.0*

Possible causes for the reduction in high z scores in method A include reduced temporal resolution and smoothing of signal from the correction procedure. Examination of the individuals' activation suggests the very high z scores present in subject 1, method B are artefactual, occurring around the brain periphery (none of this activation survives group analysis (Fig. 4b)). Although there was no significant difference in the raw voxel z scores between methods B and C a higher level group analysis of all 10 subjects produced very different results (Fig. 4) with only 1 significant ($z > 2.0$, $p < 0.05$) cluster resulting from method B (Fig. 4b) and 9 significant clusters from method C (fig. 4c). Possible reasons for the superiority of method C include the extra registration step with all timepoints undergoing registration to the selected pre-scan image, superior distortion correction due to optimal pixel shift transformation derivation from chosen pre-scan image pair and less variation between corrected time points due to an identical (pre-defined) correction being applied to every time point, instead of a separate correction for each image pair in methods A and B. With methods A and B, haemodynamic response information is smeared out in time across both images of the interleaved pair during correction, resulting in an effective TR of 6.4 ms, while method C retains the original TR of 3.2 ms.

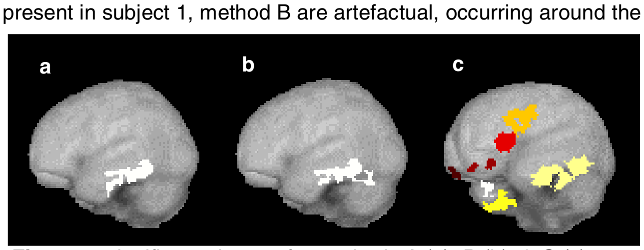

Figure 4. *significant clusters for methods A (a), B (b), & C (c), each cluster coloured individually (z > 2.0, p < 0.05).*

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References (1) Bowtell, R.W., et al. Proc. of the 2nd Annual Meeting of ISMRM. 1994. San Francisco, (2) Morgan, P.S., et al., J Magn Reson Imaging, 2004. 19(4): p. 499-507. (3) Devlin, J.T., et al.,. Neuroimage 2000, 11: p. 589-600.