Activation Signal Recovery in fMRI using an Efficient Signal Drop-Out Correction Method

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Introduction: EPI suffers from signal loss due to through-slice B_0 inhomogeneity. The BOLD activation signal detected by functional MRI is intrinsically linked to the EPI signal value. Long echo times required for optimal BOLD contrast lead to increased signal-loss preventing many regions of interest from being investigated using fMRI. Signal loss can be corrected by the z-shim[1] method but multiple z-shims of unknown value are required for full correction, making the technique inefficient. Methods have been developed to increase the speed of z-shim acquisition while maintaining good correction[2,3,4] and some have been applied to fMRI studies[5,6,7]. However, achieving good signal correction while maintaining temporal resolution and image quality is a problem. A method which requires only two z-shim images combined with an efficient calibration procedure for optimal z-shim choice was developed[8]. Here it is applied for the first time to a language fMRI study which suffers from signal loss, demonstrating activation signal recovery.

Methods: Experiments were conducted using a Philips 3T Achieva system with IFIS stimulus presentation, and processed in IDL and Matlab. 12 volunteers were imaged with whole-brain coverage (3mm slices, TE = 35ms, TR = 3s, $\theta = 90^{o}$) using single-shot EPI. Prior to the activation experiment 4 z-shimmed images per slice were acquired for sparse calibration (total duration = 18s). These data were then processed in-line to determine the optimum two z-shims to acquire during the fMRI experiment[8]. The processing (duration = 2 mins) was performed during the acquisition of the anatomical dataset. Functional data to test the two z-shim correction method against conventional fMRI was then acquired with the two calculated z-shim values and conventional acquisition interleaved to enable comparison. Volunteers were presented with a block paradigm of descriptive text passages and an odd/even number decision designed to activate the basal temporal lobe[9] where there are large areas of signal loss due to the proximity of the auditory canals. Consecutive z-shim images were combined by sum of squares. The resulting z-shim time series and the conventional dataset were processed using SPM2, both on a single-subject level and by random effects analysis, and compared.

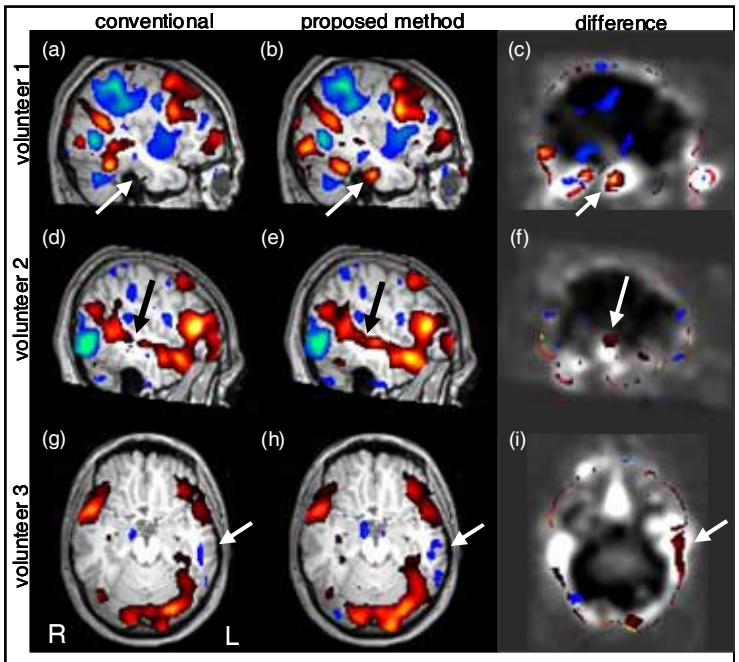

FIGURE 1: Single subject data from 3 different volunteers.

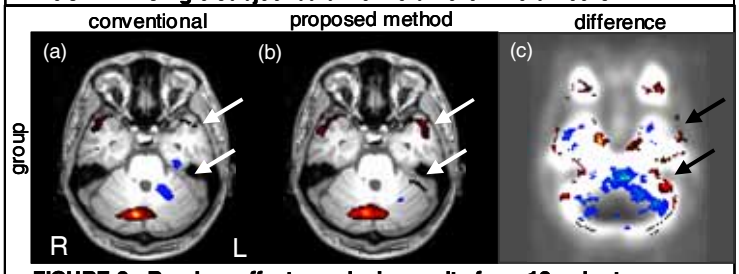

FIGURE 2: Random effects analysis results from 12 volunteers.

Results: Activation was detected by the proposed method which was either not seen, or was weaker, in the conventional method results. Sensitivity was increased by up to 93% in regions of signal loss; however, a loss of sensitivity of up to 7% was detected in regions where there was no susceptibility-driven signal loss in the conventional image. Single subject data from three different volunteers is shown in figure 1 with arrows indicating the main activation signal recovered by the correction method. T-value maps of conventional activation (left column) and the activation detected by the proposed method (middle) are shown with the contrast of text over numbers (hot colours positive, cold negative), at a significance level of $p < 0.001$ overlaid onto anatomical images. The right column shows the difference between the moduli of the activations detected by the two methods, (hot colours |proposed method activation| > |conventional activation| and cold colours vice-versa), overlaid on EPI signal recovered by the proposed method (correction method – conventional). The sagittal images are from the left of the brain. Figure 2 shows a slice of the group study random effects map; activation ($p < 0.001$) from (a) conventional images and (b) the proposed method, and (c) results of a paired t-test between the modulus group activation of the two methods ($p < 0.05$, hot colours show |proposed method activation| > |conventional activation|, cold colours vice-versa) overlaid on the average EPI signal recovery by the proposed method for the group. In all volunteers the correction method recovered EPI signal around the frontal sinus, auditory canals, base and edges of the brain which lead to detection of activation in these regions. The language study effect of interest (text over numbers) was recovered in the inferior and lateral areas of the left temporal lobe (e.g. 1(b, e), 2(b)) which are regions expected to be activated in language processing.

Discussion: The method recovered activation signal in regions of B_0 inhomogeneity revealing language processing activation not detectable by conventional fMRI. The amount, extent and placement of EPI signal loss in conventional images, and therefore the signal recovery achieved by the correction, vary between volunteers depending on head geometry and orientation relative to B_0. Additionally activation patterns differ, causing a large variability between volunteers in the amount and position of activation signal recovered. Due to this the gains of the proposed method seen at the single subject level are diluted in the group results for the small population studied. The increase in activation detection in regions of signal loss must be weighted against the slight sensitivity reduction in areas of main field homogeneity, however the proposed approach suffers less from this than methods where only a single z-shim gradient[10] is applied. Optimal z-shim values are obtained automatically from an 18s calibration scan which is readily integrated into the workflow of fMRI. As implemented the method used whole-brain calibration with acquisition of the same z-shim values for all slices, but there is potential for further signal recovery through slice-by-slice optimisation. The technique can be combined with parallel imaging for even greater efficiency. Activation signal recovery is not limited to any particular brain region, so would benefit any fMRI study with through-slice signal loss problems.

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