Statistical Combination of Partial k-Space EPI for BOLD fMRI

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Introduction. The spiral-in/out technique has been proposed recently for the improved detection of BOLD fMRI [1]. Activation volumes are increased over simple averaging using a statistically weighted combination of two activation maps each separately derived from the spiral-in and spiral-out images [2]. We propose application of the same concept to EPI: The upper half k-space in EPI (pre-TE) is analogous to spiral-in, the lower half to spiral-out. From each half we then form a complete image using homodyne reconstruction [3]. These two EPI images are combined using their individual activation map as weights. While thermal noise in the two half-images is uncorrelated except near the k-space origin, physiological fluctuations can cause correlated noise to appear across the entire readout. Thus combination of two magnitude images, each containing noise uncorrelated with the other, may result in less noise than conventional EPI and can improve contrast-to-noise ratio (CNR) and fMRI activation. Further, susceptibility dropout may be lower overall in the combined image due to adaptive combination [1].

Methods. A conventional single shot EPI is used for breath-holding fMRI scans. Raw data is gridded on a 64x64 matrix to account for non-uniform spacing during k-space acquisition [4]. A conventional EPI image is first reconstructed by Fourier transformation of the raw data. Then upper and lower k-space images are reconstructed separately by homodyne: the upper-half image corresponding to the upper 65% of the windowed raw data matrix, the lower-half image to the lower 65%. Eight lines are windowed from center k-space, extracted for phase correction of both images.

The breath-holding experiment was carried out at 3T (GE Signa, Cv/Nv gradients). This task consists of 15s normal breathing and 15s breath-holding after inspiration, visually cued and repeated for 8 cycles. This causes a systemic hypoxia and results in BOLD signal modulation, independent of cognition, having a trough during breath-holding epochs [5]. Six axial slices are gathered using an fMRI head coil (TR/TE/α /TH/FOV = 1s, 30ms, 70°, 4mm, 22cm). Correlation coefficient maps are formed by cross-correlating image time-series for each pixel with sine and cosine functions at the fundamental task frequency. This correlation analysis is performed using full k-space data, and then again using upper and lower k-space data. A *sigma filter* is used to cluster pixels in a 3x3 region thereby reducing single-voxel false positives [2,6]. Finally, the upper and lower k-space images are combined, weighted by their correlation coefficient maps.

Results. Figure 1 illustrates the correlation coefficient maps using conventional EPI reconstruction overlaid on two T2-weighted images. Figure 2 shows data from the same acquisition but processed using our new upper/lower k-space EPI technique to generate the correlation overlays. The superior curve in Fig. 3 is a histogram of pixel correlation corresponding to activation in both image slices from Fig. 2; likewise, the inferior curve in Fig. 3 corresponds to Fig. 1.

Discussion. We developed a technique to enhance EPI fMRI data by performing homodyne reconstruction to make upper and lower EPI images then combined; weighted by their individual correlation coefficient maps. The combined upper/lower EPI activation maps shown in Fig. 2 has significant activation improvement over the conventional EPI image. Unlike spiral in/out where the improved CNR comes from lengthening the readout duration, noise reduction in combined upper/lower EPI originates from the elimination of correlated noise between the two halves. Since breath-holding induces robust global activation [5], higher activation volumes indicate superior reconstruction technique indeed. While the homodyne technique is suitable for this image slice, scans near air/tissue interface regions cause rapid phase variations and k-space DC-component shift. In that situation, other partial k-space reconstruction techniques such as POCS may perform better. This method, nevertheless, may offer significant improvements for fMRI in analogy to the spiral-in/out technique.

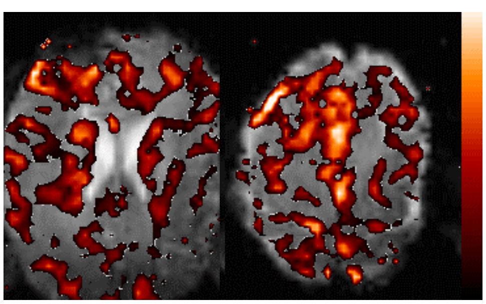

Fig. 1. Breath holding activation maps in two slices using conventional EPI reconstruction.

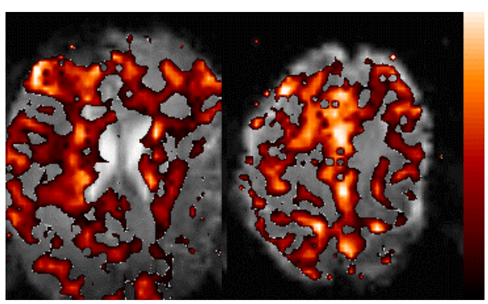

Fig. 2. Same slices as Fig. 1 but with activation maps calculated by combining two upper/lower EPI images.

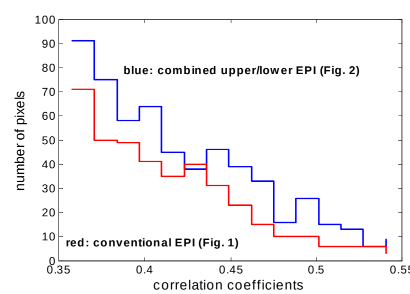

Fig. 3. Histograms of total correlation coefficients for activated pixels displayed in Fig. 1 and 2.

Reference.

1. Glover GH, Law CS, Magn Reson Med. 2001; 46(3):515-22. 2. Glover GH, Thomason ME, Improved Combination of Spiral-In/Out Images for BOLD fMRI, Magn Reson Med. (in press). 3. Noll DC, Nishimura DG, Macovski A, IEEE Trans. Med. Imag. 1991; 10(2):154-163. 4. Jackson J, Meyer CH, Nishimura DG, Macovski A, IEEE Trans. Med. Imag. 1991; 10(1):473-478. 5. Kastrup A, Krèuger G, Glover GH, Neumann-Haefelin T, Moseley ME, Magn. Reson. Med. 1999; 42(3):608-611. 6. Glover GH, Lai S, Magn. Reson. Med. 1998; 39(3):361-368.

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