Robust BOLD activation outside visual and motor cortex during a simple visual and motor task detected by whole-brain T2-prepared spin-echo (SE) BOLD fMRI at 7T

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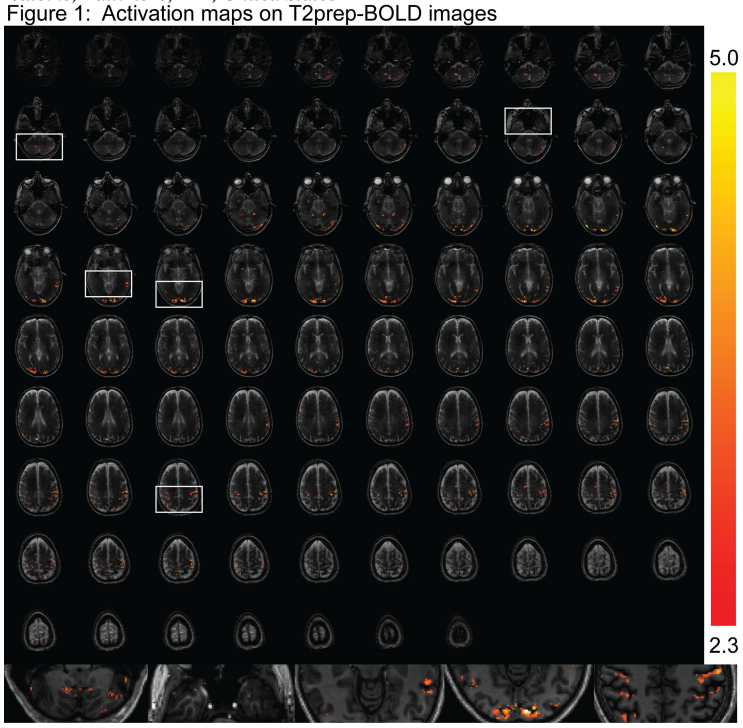
TARGET AUDIENCE: Researchers interested in fMRI.

PURPOSE: Most fMRI studies in the literature report localized BOLD activations only in brain regions of primary relationship to the stimulation, for instance the visual or motor cortex during flashing checkerboard or finger tapping tasks, respectively. Nevertheless, a recent study using a visual plus letter/number discrimination task shows that BOLD activities can be detected in almost the entire brain when noise is dramatically reduced by massive averaging (1). Therefore, whole brain fMRI is important for the understanding of human brain functions. In conventional echo-planar-imaging (EPI) based BOLD fMRI, it is well known that images in brain regions close to air cavities, such as the orbitofrontal, inferior and medial temporal cortex, suffer from severe signal dropout and distortion, especially at high magnetic field. Even in regions where complete signal dropout is avoided, its BOLD sensitivity is much diminished (2). Here, we employed the T2-prepared spin echo (SE) BOLD fMRI approach (3), which has been shown to have minimal dropout and distortion at 7T. Whole-brain fMRI experiments were performed with simultaneous flashing checkerboard and bilateral finger tapping using gradient-echo (GRE) EPI, SE-EPI and T2-prepared SE BOLD fMRI at 7T. With each method, the fMRI experiments were repeated for a full hour and averaged to improve signal-to-noise ratio (SNR). In addition to activations in the visual and motor cortex observed in all three methods, several other regions including the frontal and temporal lobes also showed significant BOLD activities in T2prep-BOLD images, but not in GRE/SE-EPI images. We attribute this mainly to the fact that the contrast-to-noise ratio (CNR) in these regions was greater in T2prep-BOLD, possibly due to much reduced dropout and distortion, thus preserving BOLD sensitivity. These results imply that information in these brain regions might be neglected with EPI based BOLD methods, which is important especially for fMRI studies using more sophisticated cognitive tasks.

Figure 1: Activation maps on T2prep-BOLD images



METHODS: *T2-prepared SE BOLD fMRI* (3) employs a 3D fast GRE (also known as turbo field echo, TFE, or TurboFLASH) sequence as the readout, which has much less distortion and dropout than EPI, and low power deposition, and is commonly used in high resolution anatomical scans such as MPRAGE. The SE BOLD contrast is induced with a T2-preparation module applied immediately before the readout. *Experiments* were performed on a 7T Philips scanner. A 32-channel phased-array head coil (Nova) was used for RF reception and a head-only quadrature coil for transmit. Visual stimulation was delivered using flashing checkerboard (39.9s off/26.6s on, 4 repetitions for each run). The subjects were instructed to perform bilateral finger tapping during the flashing periods. Same geometry was used for all fMRI scans: 87 slices, voxel=1.5mm isotropic. Three fMRI methods were used, and TRs were adjusted in each method to accommodate all 87 slices under the maximum power limitation: (a) 2D GRE EPI, TR=6.5s, TE=50ms, FA=90º, SENSE=3, fat suppression. (b) 2D SE EPI, TR=13.3s, TE=50ms, FA=90º, SENSE=3, fat suppression. (c) 3D T2prep-BOLD, TR=1.9s, T2prep effective TE=80ms (double refocusing), FA=4º, SENSE=3x3(APxFH), centric phase encoding. With each method, fMRI experiments were repeated for 12 runs (1 hour total time) and averaged. Optimal higher-order shim was applied in both EPI scans. Anatomical images were acquired using MPRAGE. *All fMRI analysis* was carried out with SPM8 and Matlab6 (general linear model, P<0.01, cluster size ≥4). Temporal SNR (tSNR) was calculated as the signal divided by standard deviation along the time course during the off periods. CNR was defined as: relative signal change between activation and rest (ΔS/S) x tSNR.

Figure 2: (a) Visual+Motor (b) Frontal+Temporal

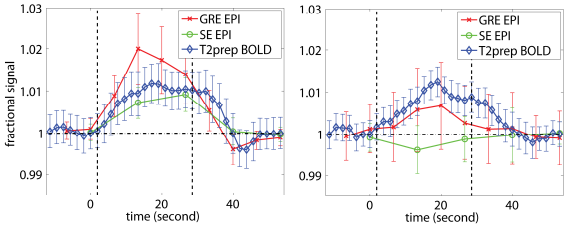


Table 1.	ΔS/S(%)	tSNR	CNR
Visual+Motor			
GRE EPI	2.07±1.32	261±56	5.4±3.4
SE EPI	1.06±0.63	263±58	2.8±1.5
T2prep-BOLD	1.12±0.64	271±49	3.1±0.7
Frontal+Temporal			
GRE EPI	0.62±0.66	188±51	1.1±1.0
SE EPI	-0.35±0.74	191±56	-0.6±1.1
T2prep-BOLD	1.03±0.56	195±48	2.0±0.4

RESULTS: Fig. 1 shows a thresholded activation map using T2prep-BOLD fMRI overlaid on T2prep-BOLD images, which showed little dropout and distortion, and resemble anatomical images. Several activated regions are also zoomed at the bottom. Significant activations were observed in the visual and motor cortex, as well as in regions in frontal and temporal cortex, other basal regions of the brain, and the cerebellum. Most of these regions other than the visual and motor cortex did not show significant activation in GRE/SE EPI scans (figure not shown). Fig. 2 shows average time courses from (a) common activated voxels from all three methods in the visual and motor cortex and (b) from activated voxels in the frontal and temporal cortex that reached statistical significance for activation *only* in T2prep-BOLD. Quantitative results are summarized in Table 1. tSNR was comparable for all three methods (same total scan time). Note that even in regions with severe distortions in EPI images, tSNR did not drop drastically, mainly because physiological noise is dominant in fMRI data. However, ΔS/S in these regions greatly diminished, leading to CNR that was not significantly elevated from zero. Meanwhile, T2prep-BOLD showed preserved CNR that was sufficient to detect BOLD activities in these regions.

DISCUSSION: It is not surprising that multiple brain regions along the visual and motor pathways may be involved even in a simple visual and motor task such as the one used here. For instance, in our data, regions in the temporal lobe showed significant activation, which has been postulated to be involved in the visual pathway for processing information necessary to recognize objects and colors. T2prep-BOLD fMRI provides a useful method with preserved CNR in regions that are almost inaccessible in EPI BOLD methods due to severe dropout and distortion. Note that even in regions with acceptable signal intensities (similar tSNR), the susceptibility gradients that cause EPI distortion may alter the local TE, thus compromising the BOLD sensitivity in EPI images (2). The three methods were compared with identical spatial resolution, coverage and total scan time. CNR in these regions in EPI images may be improved by averaging more fMRI runs, which will lengthen the total time.

CONCLUSION: We showed that T2prep-BOLD has greater CNR than GRE/SE-EPI in brain regions close to air cavities, which allowed it to detect some subtle BOLD activations in these regions that were not shown in GRE/SE-EPI scans. This suggest that T2prep-BOLD may be a useful method for whole-brain fMRI studies at 7T, especially when brain activities in these regions are important, or when it is unclear which brain regions should be involved in sophisticated tasks.

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