BOLD Contrast Sensitivity Enhancement and Artifact Reduction with Parallel-Acquired Inhomogeniety Desensitized (PAID) fMRI

B. A. Poser[1], D. G. Norris[1]

[1]FC Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands

Introduction

Functional MRI generally employs gradient-echo echo planar imaging (EPI) to measure the BOLD contrast between the active and resting states of the brain. Since this contrast results from small variations in the relaxation time T_2*, sensitivity is optimal only where echo time matches the local T_2* average. Thus, given the large range of T_2* across the brain, single echo fMRI always means a compromise in overall sensitivity. Furthermore, conventional EPI is prone to strong geometric distortion and signal dropout, which often requires use of a sub-optimally short TE to avoid signal loss in inferior brain regions, e.g. in hippocampus studies. Using parallel imaging to shorten echo train length, PAID fMRI acquires multiple echoes (ME) to overcome this problem and broaden sensitivity to a wide range of T_2* without the need to increase repetition time. Echoes are combined by a pixel-wise weighted summation according to the expected BOLD contrast curve for the local T_2*, which can be extracted either from the echoes themselves, or better, a FLAIR measurement which suppresses the unwanted contribution of cerebro-spinal fluid. Due to shorter echo trains, distortion effects in PAID fMRI are reduced significantly.

Using a Stroop task paradigm we demonstrate that weighted summation increases the BOLD sensitivity across the whole brain as compared to the individual echoes, and that from early echoes signal in inferior regions becomes available that drops out with conventional imaging at a single TE.

Methods

The ME-EPI sequence uses the standard readout, but records any number of echoes at selectable echo times. Phase encoding order is kept the same to ensure constant distortion. The FLAIR sequence only differs in that it is preceded by an inversion pulse to suppress the CSF signal which usually leads to overestimation of T_2*. Both sequences were implemented on a Siemens Magnetom Trio 3T system (Siemens Medical Solutions) equipped with an 8-channel head receive coil. Brain activation was evoked by a Stroop color-word matching task as described in [2]. Parameters for the functional scans were: conventional imaging (single echo at TE=35ms), acceleration factor 2 (3 echoes at 15, 37 and 58ms) and acceleration factor 3 (5 echoes at 12, 27, 42, 56 and 71ms). All scans used matrix size 64x64, 25 axial slices, 3.5mm isotropic resolution, bandwidth 1816Hz/pixel, flip angle 90° and TR=2.5s with total scan time of 14min. GRAPPA reconstruction [3] was used for ME recordings. T_2* maps were obtained at acceleration factor 2 (6 echoes) and 3 (9 echoes) using the FLAIR EPI sequence (TI=2s, 5 averages, scan time ~1min), or 'on-the-fly' from each functional volume itself by a fast numerical method [4]. The pixel-wise weighted summation of the echoes was performed with the normalized filter $TE_i/T_2^* \cdot \exp(-TE_i/T_2^*)$. This maximizes contribution of the echoes close to the local T_2* and therefore BOLD sensitivity, by minimizing the addition of noise [1]. Simple echo summation and statistical analysis on the T_2* maps of each volume themselves was used for comparison. Images were realigned in SPM2 (http://www.fil.ion.ucl.ac.uk/spm/), and standard t-statistics for all task conditions against baseline was performed in Brainvoyager (Brain Innovation, The Netherlands).

Results and Discussion

For most clusters, pixel-by-pixel weighted summation results in higher t-scores than those apparent in the individual echoes and by simple summation, which can be attributed to the contrast enhancing nature of the weighting filter in PAID fMRI. Weighted summation based on the T_2* map of each volume itself provided only marginal gains, while weighting based on FLAIR T_2* maps shows some additional activation clusters that are invisible both in the individual echoes and summed image at the same significance threshold (Fig.1). Statistics on the time-course T_2* maps as first suggested in [5] returned less significant, albeit 'complete', activation maps. Visual inspection of the PAID images at both acceleration factors clearly shows the expected reduction in distortion and dropout compared to the single conventional echo. First results indicate that activation in inferior regions becomes visible which is typically lost due to through-plane dephasing and blurring (Fig. 2), while sensitivity is simultaneously enhanced for more superior regions. For the small number of subjects (n=6) quantitative assessment is difficult due to habituation effects and strong inter-subject variability. As shown in [1], simple summation should not perform much worse than weighted summation as long as total sampling time does not exceed the optimum of $3.2 \cdot T_2$*. However, this condition is not always fulfilled for very short T_2* in inferior regions. Although significant, the sensitivity gain obtained from the proposed weighting strategy does not show the gains expected from pure SNR considerations, which indicates that physiological noise in the time series dominates over thermal and reconstruction related noise.

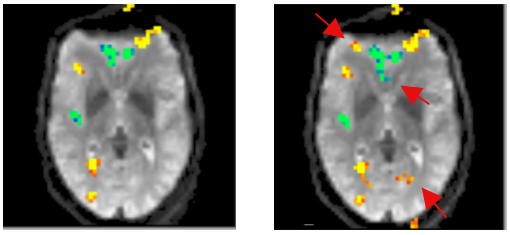

Fig. 1 *Un-weighted (left) and weighted summation based on FLAIR T_2* map (right). Arrows indicate clusters only visible with pixel-wise echo weighting (acc=2).*

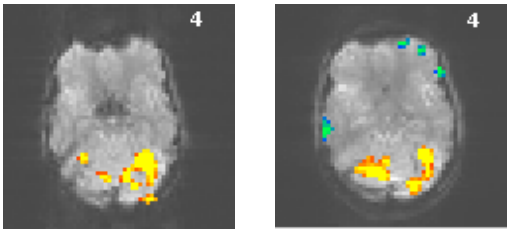

Fig. 2 *Conventional EPI (left) and PAID image at acc=3 (right). Pre-frontal deactivation that is typically lost is detectable with PAID fMRI.*

As the implementation for online reconstruction on the scanner is straight forward and the combined images can be treated in the same way as conventional data, PAID fMRI is suitable for operator-independent use and could in the future well become the method of choice for functional experiments.

References

[1] Posse S et al, Magn Res Med 1999;42:87-97; [2] Norris DG et al, NeuroImage 2002; 15:719-726; [3] Griswold MA et al, Magn Reson Med 2002;47:1202-10; [4] Hagberg GE et al, Magn Reson Med 2002;48:877-882; [5] Speck O et al, Magn Reson Med 1998;40:243-8.