HASTE sequences for functional MRI: BOLD and VASO

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Introduction

Multiply-refocused sequences such as HASTE are attractive for functional MRI (fMRI) as they are free of susceptibility artifacts, and yield pure T2 contrast. The latter can be advantageous for two fMRI applications: First, spin echo (SE) based fMRI. SE reportedly offers better spatial localization of the BOLD signal, but is most commonly used in combination with a long EPI readout, resulting in residual T2* and static averaging contributions. Second, cerebral blood volume (CBV) measurements. The recently proposed Vascular Space Occupancy (VASO) uses IR-EPI and is thus prone to T2* / BOLD contamination of the measured CBV signal. Here, short TE IR-HASTE should offer both higher signal-to-noise and minimal BOLD contribution.

We investigate both applications of HASTE in fMRI at 3 T, using visual and emotional (amygdala) stimulation paradigms.

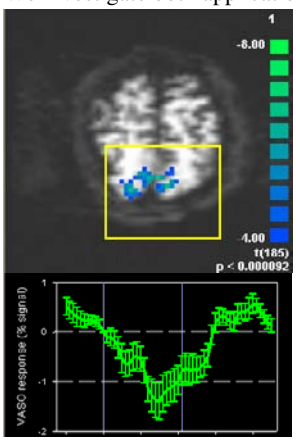

Fig. 3 *VASO activation overlaid on HASTE VASO image (top) and typical biphasic HASTE VASO signal timecourse*

Theory

BOLD fMRI: SE sequences are sensitive to intra-vascular T_2 changes and dynamic dephasing effects near small vessels. Increased dynamic averaging improves the spatial specificity of fMRI [4, 5]. In SE-EPI functional sensitivity decreases by a factor of 3 compared GE-EPI, but residual T2* weighting is likely to remain due to the long EPI acquisition window (typically 40 ms). The HASTE BOLD signal will be free of static dephasing contributions, and can thus be expected to further improve specificity. To maximize dynamic averaging the first spin echo should be formed at TE equal to gray matter T2 ~ 80ms, followed by rapid turbo spin echo like k-space sampling in a centre-out fashion. However, sequential sampling with a shortened T2 preparation period can be used to reduce the total image acquisition time. *VASO fMRI:* VASO uses an inversion recovery preparation to selectively null the blood signal, resulting in a negative signal change with increasing blood volume during brain activation. Conventionally used with EPI, the VASO signal is prone to contamination by (counter acting) BOLD like signal contributions which arise due to the fact that the EPI echo train length precludes use of a sufficiently short (ideally zero) TE. HASTE allows minimal TE sampling, and can further be expected to have better SNR and more benign point spread function.

For both applications, the main attraction of HASTE is that the images are free of inhomogeneity artifacts.

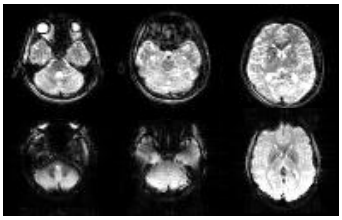

Fig 1: *T_2 weighted HASTE (top) and corresponding EPI images (bottom)*

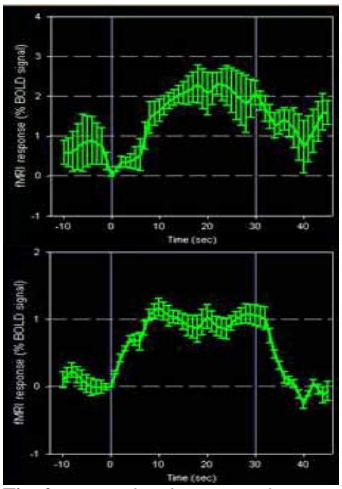

Fig. 2 *Event related average of amygdala activation in one subject as detected with HASTE (top) and EPI (bottom).*

Methods

BOLD fMRI: We implemented a HASTE sequence which refocuses the first echo at 50ms, followed by sequential echo acquisition such that the k-space centre is acquired at the 'target' TE of 80ms. Factor-4 GRAPPA parallel imaging in combination with 7/8 partial Fourier allowed reduction of the pulse (echo) train length to 14 for an acquisition matrix of 64x64 (3.5x3.5x5mm^3 voxels), and a sampling time of only 150ms per slice. Reference data for the parallel reconstruction were acquired in a pre-scan. The drastic undersampling was necessary to meet timing and SAR constraints, and to avoid magnetization transfer effects that as a result of high energy deposition would otherwise lead to strong attenuation of gray and white matter signal. Flip-angle was 160º. Visual stimulation experiments (blocked, 21/30s on/off, 7min scan) were performed on 4 subjects. Single- (n=2) and 5-slice (n=2) data were acquired with TR=2s. Amygdala activation was induced in two subjects using emotional stimuli (blocked 30/30s on/off, 7min scan, 5 slices). GE-EPI scans (TE=35ms) were acquired as a reference. *VASO fMRI:* CBV measurements with fully sampled IR-HASTE (TE=6ms, TI=710ms, TR=2s) were performed on 3 subjects using the same visual stimuli. GE-EPI (TE=35ms) and EPI VASO (TE=14ms) were acquired for reference. Analysis was done in Brainvoyager. Sensitivities were measured in terms of CNR (signal change over average standard deviation from event related response curve), and average t-scores.

Results and Discussion

BOLD fMRI: For the visual stimulation experiment, average CNR and t-scores are reduced to 64±19% and 50±18% respectively as compared to GE-EPI; in the amygdala (medial temporal lobe) CNR and t-scores reduced to 65±18%, and 33±4%, respectively (Fig. 2). Sensitivity reductions are expected due to absence of (extra)vascular dephasing contributions in the SE. The measured values suggest that T2 weighted HASTE has sensitivity equal to or better than SE-EPI for which a relative BOLD sensitivity of only 30% w.r.t. GE-EPI has been reported [1]. Image quality drastically improves with absence of the EPI artifacts (Fig. 1). Further improvements in sensitivity and sampling speed can be expected from e.g. the use of variable flip angle schemes. *VASO fMRI:* CBV could be well reproduced with VASO HASTE. On average CNR *increased* from 3.7±2.1 to 6.2±1.5. The biphasic CBV response also present in previously published data is more apparent in the HASTE scans (Fig. 3). From the improved sensitivity it appears that VASO HASTE should be the method of choice for studying the temporal dynamics of CBV changes.

References

[1] Parkes LM et al, Magn Res Med 2005, in press; [2] Lu H et al, Magn Reson Med 2003;50(2):263-274; [3] Griswold MA et al, Magn Reson Med 2002;47:1202-10; [4] Norris DG et al, Neuroimage 2002;15(3):719-726; [5] Jochimsen TH et al, Magn Reson Med 2004;52(4):724-732