High Resolution BOLD fMRI Using mHASTE

Y. Ye[1], Y. Zhuo[1], and X. J. Zhou[2]
[1]State Key Laboratory of Brain and Cognitive Science, Institute of Biophysics,CAS, Beijing, Beijing, China, People's Republic of, [2]University of Illinois Medical Center, Chicago, Illinois, United States

Introduction:

Recently, a novel BOLD fMRI method based on a modified half Fourier single shot TSE technique, namely mHASTE, has been explored and discussed [1,2]. In comparison with the widespread EPI sequences (e.g. GE- and SE-EPI), mHASTE offers artifact- and distortion-free functional images, higher signal-to-noise ratio (SNR) and potentially better function specificity, while achieving comparable scanning speed and significant activation [1]. mHASTE in design features in pure T_2 weighted signal, and when used for fMRI study, features in BOLD contrast arising from extravascular (EV) dynamic averaging effects and venous blood T_2 changes. One great potential of mHASTE is its capability to acquire high resolution functional images, thanks to the high SNR, low readout bandwidth and the use of multiple refocusing pulses to eliminate any accumulative background field effects. The purpose of this study is to demonstrate mHASTE's capability for high resolution (HR) BOLD fMRI, and in comparison with GE- and SE-EPI, to explore mHASTE's BOLD signal characteristics with increasing spatial resolution.

Methods:

Three healthy volunteers with written consent participated in this study. Visual stimuli consisted of 3 blocks of 20s rest followed by 20s of 8Hz flickering B&W checkerboard. All data were acquired on a Siemens Tim Trio 3T system (Siemens Medical Solutions, Erlangen, Germany) with a product 12-channel head coil. mHASTE sequence as described in previous works [1] was used (Fig. 1), with scanning parameters as: TR/TE=3000/82ms, FOV=220mm, T_p=50ms, echo spacing=6.42ms and 8 slices covering the visual cortex. To achieve a temporal resolution comparable to EPI as well as reducing SAR, GRAPPA [3] was used with 3x acceleration, resulting in a 15-echo ETL. For comparison, fully sampled GE-EPI and SE-EPI BOLD images were also acquired with parameters close to those used in the mHASTE sequence, except for that TE=30ms and excitation angle=70° (the Ernst angle) for GE-EPI and TE=80ms for SE-EPI. For each sequence, both 64x64 and 128x128 data were acquired. The scanning order of different sequences was randomized for each subject to remove any systematic errors. All images were processed using SPM5 in combination with in-house Matlab programs. SNR maps were calculated based on spatially realigned images. Functional results were then spatially normalized to an ICBM-defined T_1 standard space, followed by analysis of the activated cluster size, the t-scores and the functional contrast (i.e., ΔS/S). An activation threshold of $p<0.05$ was used with family-wise error (FWE) estimation for all data.

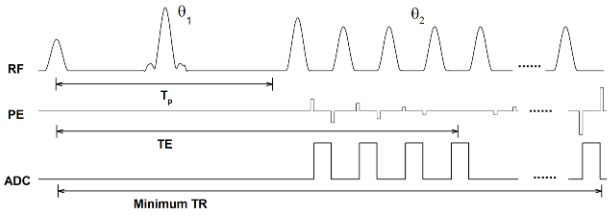

Fig.1 Diagram of mHASTE. T_p was introduced to enhance dynamic averaging. θ_1 and θ_2 were 180° refocusing pulses.

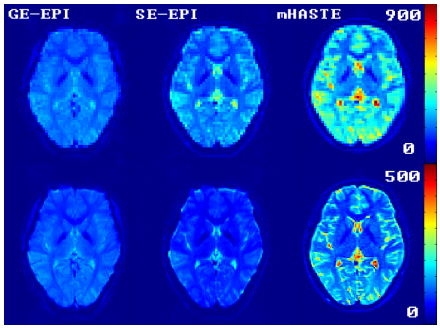

Fig.2 SNR maps of GE-EPI (left), SE-EPI (middle) and mHASTE (right) images of low resolution (i.e. 64x64, upper row) and high resolution (i.e. 128x128, bottom row). Intensity display range is the same for each row, as shown by the color scale bar on the right

Table. 1 The activated cluster size, the t-scores and the functional contrast ΔS/S results of 3 subjects. LR stands for low resolution of 64x64, and HR for high resolution of 128x128.

		Subject 1			Subject 2			Subject 3		
		GE-EPI	**SE-EPI**	**mHASTE**	**GE-EPI**	**SE-EPI**	**mHASTE**	**GE-EPI**	**SE-EPI**	**mHASTE**
Cluster size (voxels)	LR	8882	5625	481	10558	11512	1383	2129	2736	2995
	HR	4797	2571	663	8327	8575	2474	481	645	1637
	HR/LR(%)	54.0%	45.7%	137.8%	78.9%	74.5%	178.9%	22.6%	23.6%	54.7%
t-score (mean±STD)	LR	8.78±7.05	8.74±5.10	6.19±0.45	8.37±6.3	9.10±7.49	6.40±0.61	6.09±0.37	6.55±0.44	7.01±1.70
	HR	7.45±3.48	6.87±1.22	5.92±0.29	7.78±4.51	8.22±4.18	6.81±1.43	5.63±0.13	6.08±0.25	6.85±1.04
ΔS/S (%)	LR	3.31	1.60	1.46	2.45	1.08	1.43	3.24	1.22	1.28
	HR	3.27	1.63	2.08	2.39	1.34	1.34	1.92	1.34	1.90

Results:

The SNR maps for all three sequences at both resolutions are shown in Fig.2, and the activation statistics of the three subjects are listed in Table 1. For subjects 1 and 2, mHASTE resulted in smaller activation cluster than both EPIs; however, when going from LR to HR, the cluster size increased in mHASTE while decreased in both EPIs. For subject 3, cluster size decreased in all three sequences, but the decrease in mHASTE is much smaller than the EPIs (also note that for this subject, the activation cluster was largest with mHASTE for both LR and HR). For functional contrast ΔS/S, GE-EPI tends to have decreased value for HR data, while SE-EPI and mHASTE tend to have unchanged or increased values.

Discussion and conclusions:

Consistent with previous literature [1], mHASTE yielded a higher SNR than both EPIs for both LR and HR data, especially in the grey matter, which is profitable for maintaining sufficient functional CNR. The most interesting phenomenon observed in this study was that mHASTE behaved very differently from those of GE- and SE-EPI when going from LR to HR, while both EPIs behaved largely similarly. The results in Table.1 suggest that mHASTE is capable of more robust functional detection at higher resolution. As the main BOLD contrast mechanisms of mHASTE are diffusion-based EV dynamic averaging effects and apparent T_2 changes of venous blood [1,4], they virtually do not change with the size of the voxel. Therefore, if assuming an unchanged CNR, the voxel number at HR will be four times as large as at LR. However, as SNR is also reduced (Fig. 2), the increase in activated voxels will be reduced from the ideal factor of 4. On the other hand, due to the longer gradient readout and thus a further reduced SNR, as well as the partial volume effect dependent T_2* related BOLD contrast [4], the EPIs resulted in smaller activation clusters at HR. However, if we compare the HR/LR ratio between mHASTE and both EPIs, it is very similar for all 3 subjects, i.e. 137.8%/45.7% ≈ 178.9%/74.5% ≈ 54.7%/23.6% (mHASTE vs. SE-EPI) and 137.8%/54.0% ≈ 178.9%/78.9% ≈ 54.7%/22.6% (mHASTE vs. GE-EPI). This suggests a close connection between these changes, which requires further studies to understand. The different contrast mechanisms of the sequences [1] can also explain the ΔS/S changes from LR to HR, which roughly follows that mHASTE (increase) > SE-EPI (slight increase) > GE-EPI (decrease). Subject 3 represented a very interesting case where mHASTE could result in larger cluster size as well as similar or even larger ΔS/S than EPI sequences. Such phenomenon has also been observed in some of our preliminary tests (not shown), and with further study may possibly reveal important information about the affecting factors to the routinely observed individual variations of BOLD fMRI results. In conclusion, we have demonstrated that mHASTE would result in a more significant BOLD functional contrast at higher resolution. Further work should involve a larger scale of data acquisition and analysis, and a deeper look into the functional contrast mechanisms between mHASTE and EPI, statistically and individually.

References:

[1]Yongquan Ye, Neuroimage, 2009; [2] Poser, Magma, 2007; 20(1):11-17; [3] Griswold, MRM, 2002;47:1202-1210; [4] Yacoub, Neuroimage 2005:24(3):738-750