Hypercapnia as a global fMRI stimulus at 1.5T and 3T: comparison of spiral imaging with cartesian parallel EPI

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Introduction: Functional MRI techniques typically utilize single-shot gradient-echo EPI to measure the blood oxygen level-dependent (BOLD) signal changes associated with stimulus-induced brain activation. Previous studies have examined the performance characteristics and relative efficacy between cartesian and spiral EPI trajectories for BOLD imaging [1]. However, more recently, cartesian EPI combined with parallel imaging strategies has been implemented to reduce sensitivity to magnetic susceptibility differences. Artifacts arising from susceptibility differences include image distortion and signal intensity dropout, and these artifacts may affect the localization and interpretation of functional MRI results. Although potential benefits of spiral EPI combined with parallel imaging may exist, the associated reconstruction is complex, time consuming and not readily available on commercial systems. The goal of this present study was to collect BOLD images in healthy adult subjects using both spiral EPI and cartesian EPI acquired with a parallel imaging strategy, to compare the relative efficacy of BOLD measurements as well as the extent of signal dropout between both techniques. To perform this comparison, we used hypercapnia as a global stimulus to enable an accurate evaluation of the magnitude and variance of BOLD signal changes across the entire brain. Furthermore, using hypercapnia stimuli allowed us to calculate the cerebrovascular reactivity (CVR), which is a reproducible measure of the BOLD signal changes relative to the patient's end-tidal CO_2 levels [2].

Methods: Five healthy male (25 - 42 years old) volunteers were imaged on both 1.5T and 3.0T GE Signa MRI systems using a single-shot gradient echo EPI sequence with both spiral EPI, and cartesian EPI combined with a parallel imaging (ASSET) acceleration factor of two. Imaging parameters for all acquisitions were: TE = 40 ms, TR = 2100 ms, flip angle = 85°, FOV = 200 mm, matrix size = 64 × 64, number of slices = 28, slice thickness = 4.5 mm, number of volumes = 230 and total acquisition time ≈ 8 minutes. High resolution T1-weighted images were acquired for each subject for image co-registration. The CO_2 stimulus in this study was provided by dynamic forcing of end-tidal CO_2 (DEF), implemented with a previously described rebreathing circuit [2]. This DEF device allowed the precise delivery of square wave changes in the partial pressure of end-tidal CO_2 ($P_{ET}CO_2$). A total of eight cycles of hypercapnia (45sec at ~ 50mmHg) with alternating cycles of hypocapnia (45sec at ~ 30mmHg) were delivered by the DEF system. $P_{ET}CO_2$ levels were monitored continuously using a commercially available capnograph and recorded digitally at a sampling rate of 60Hz/channel. Following each experiment, the full $P_{ET}CO_2$ time course was reduced to a single measurement for each breath to enable a correlation analysis with the BOLD MRI data. The image volume time series for each patient was then realigned to compensate for patient motion. We estimated the time delay between the $P_{ET}CO_2$ and BOLD time series using the BOLD signal from the entire brain to put the two parameters in phase. Once in phase, CVR map values were calculated, on a pixel-by-pixel basis, from the slope of the regression of the MR signal with the $P_{ET}CO_2$, which generated a measure of reactivity expressed in units of % ΔMR signal / mmHg CO_2. All image analysis methods were performed using AFNI (NIH, Bethesda, USA). The sensitivity of both spiral EPI and ASSET EPI techniques to susceptibility effects, specifically signal dropout, was quantitatively assessed by measuring the number of pixels with a signal greater than half the median of the entire image. Furthermore, magnitude and variance of the actual CVR measurements were quantified by calculating mean CVR values and BOLD signal-to-noise ratio (SNR). In which BOLD SNR was measured using the signal residuals following regression as an estimate of the noise. Paired Student's t-tests were performed for each parameter, at both field strengths, to compare spiral EPI with ASSET EPI.

Results: Table 1 displays results of the comparison between spiral EPI and ASSET EPI at both 1.5 T and 3.0 T field strengths. For the 1.5 T MRI results, no significant differences existed between spiral EPI and ASSET EPI for all parameters. For the 3.0 T MRI results, the extent of signal dropout was significantly reduced for ASSET EPI compared with the spiral EPI acquisition ($p < 0.05$). Visual inspection clearly demonstrates this reduced signal dropout, as well as reduced image distortion with ASSET EPI compared to spiral EPI at 3.0 T (Figure 1).

Discussion: This study demonstrated a reduced extent of signal dropout using ASSET EPI compared with spiral EPI at 3.0T, whereas no differences in the efficacy of CVR measurements existed. However, at 1.5T, there was no significant difference in signal dropout using the ASSET EPI method compared with spiral EPI, which can be attributed to reduced susceptibility effects at lower field strengths. Our results suggest that combining cartesian EPI with parallel imaging strategies will improve the quality and interpretation of functional MRI results in regions of susceptibility differences. In future, we plan to investigate larger parallel imaging acceleration factors, spiral in-out techniques [4] and post-processing image distortion correction algorithms [5] to further reduce the sensitivity of BOLD measurements to susceptibility artifacts.

References: 1. Block KT *et al*, JMRI, **21**:657-668; 2. Kassner A *et al*, ISMRM **455** (2006); 3. Vesely A *et al*, MRM, **45**:1011-1013 (2001); 4. Preston AR *et al*. NeuroImage, **21**:291-301(2004); 5. Hutton C et al, Neuroimage, 16:217-240 (2002)

	1.5 T		3.0T	
	Spiral EPI	ASSET EPI	Spiral EPI	ASSET EPI
Mean CVR (% Δ BOLD / mmHg)	0.164 ± 0.022	0.160 ± 0.010	0.266 ± 0.023	0.251 ± 0.020
BOLD SNR (%)	56.6 ± 65.4	65.4 ± 7.1	42.5 ± 5.7	49.0 ± 6.5
# of pixels above signal threshold	7240 ± 730	7260 ± 750	5930 ± 230	6690 ± 210*

Table 1. Spiral EPI compared to ASSET EPI for three metrics of BOLD imaging quality. * $p < 0.05$ between EPI techniques.

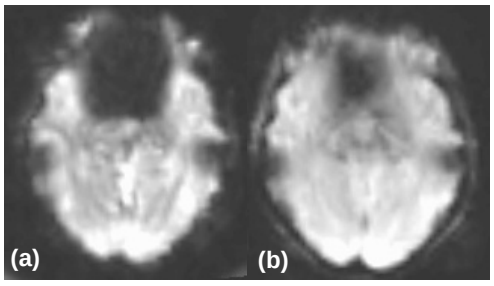

Figure 1. Single-shot GE images collected at the same slice location with (a) Spiral EPI and (b) ASSET EPI in a healthy adult subject at 3.0T.