An Optimized EPI Pulse Sequence Using SENSE for fMRI Studies of Orbitofrontal and Medial Temporal Brain Areas

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Introduction and Hypotheses Strategies to overcome susceptibility-related signal dropout in brain areas located at the skull base include: increasing spatial resolution, decreasing TE, selecting specific slice orientations, using refocusing strategies, using tailor made RF pulses, and applying compensation gradients matched to specific acquisition sequences [1]. While these strategies can reduce susceptibility artifacts, the recovery of signal loss occurs at the expense of other imaging factors (e.g., temporal resolution, spatial resolution, spatial coverage, BOLD contrast, and/or SNR). In a recent study, Deichmann et al. [2] proposed an alternative method that can compensate for the effects of both through-plane and in-plane susceptibility gradients. Their approach, uses a single-shot EPI acquisition sequence with a preparation gradient z-shim pulse (reducing through-plane effects) in combination with an optimized slice orientation (reducing in-plane effects). Deichmann et al., using a 2T scanner, demonstrated that a 30° tilt angle in combination with a preparation gradient pulse of duration τ = 1 ms and amplitude G_{prep} of –2 mT/m can recover signal in the orbitofrontal and medial temporal areas, as compared to a standard EPI sequence. Moreover, signal recovery occurred without sacrificing whole brain coverage or temporal resolution. However, while this approach can be used to recover signal from specific ROIs, signal intensity and BOLD sensitivity can be diminished. In the current study we aimed to optimize signal recovery in the orbitofrontal and medial temporal regions using the approach proposed by Deichmann et al. [2,3] at 1.5 Tesla with a SENSE head coil [4]. The SENSE head coil can be used to increase BOLD SNR if the multiple coil array is not used to reduce acquisition time. Alternatively, the fewer phase encoding steps required by the SENSE coil in its customary usage results in a reduction of susceptibility artifacts [4]. We also quantified the degree to which the optimized sequence for the orbital frontal/medial temporal areas diminishes BOLD sensitivity in other brain regions by measuring changes in the sensitivity of the BOLD signal in response to olfactory, motor, and visual stimulation. We hypothesized that the optimized sequence (30 degree tilt plus Z-shim) in combination with SENSE would: 1) reduce signal loss in the orbitofrontal and medial temporal regions, resulting in greater odor-induced BOLD activation in primary and secondary odor-related brain regions, and 2) reduce signal intensity in posterior brain areas resulting in reduced BOLD sensitivity in response to motor and visual stimulation in primary motor and visual areas.

Methods This study examined odor-, motor-, and visually-induced BOLD activation in 2 young subjects. A 1.5 Tesla Intera Philips scanner, equipped with a SENSE head coil, was used for fMRI image acquisitions. Two sequences were used to acquire data: 1) A standard, single shot EPI gradient echo sequence with a slice orientation of 30° (TR/TE=3000/40ms, flip=90°, slice thickness 3 mm with 0.5mm gap, 34 slices covering the whole brain, FOV=19×19cm^2, 64×64); and 2) an optimized sequence using SENSE with a 30° tilt plus a moderate z-shim preparation gradient (τ=2ms, G_{prep}=-1mT/m). All other parameters remained the same. T1-weighted images were acquired at the same locations to aid in anatomical localization. For each subject, 4 odor, 2 motor and 2 visual scans were acquired (4 standard and 4 optimized). Consecutive odor scans were separated by a motor or visual scan to allow for recovery from adaptation and habituation. During the odor detection scans, 6 odors (mint, clove, licorice, banana, mentol, and coconut) were presented at suprathreshold concentrations (12 sec ON and 18 sec OFF) via an olfactometer[5]. During motor scans subjects were cued to tap (i.e., fingers to thumb) for 30 sec blocks, alternating with 30 sec of rest. During the visual scans, subjects viewed three 30 sec blocks of an 8-Hz flashing checkerboard that alternated with a 30 sec. fixation cross. Total time for each scan was 3'36".

Data analysis Preprocessing and analysis of the imaging data was performed on a PC with IDL-based software. A binary mask was generated for each subject to evaluate the severity of signal-dropout caused by the susceptibility artifact. The functional volumes for each subject were co-registered with T1 weighted anatomical images. To increase the odor-induced BOLD SNR, the EPI data from the 6 ON/OFF blocks for the 2 standard scans were averaged, as were the 2 optimized scans. The first 3 blocks of the resulting datasets were then averaged with the last three blocks, yielding 3 ON/OFF odor blocks. Data from all subjects and scans were analyzed using the GLM, applied voxel-wise. For the olfaction data, contrasts examined an "early" positive component of the fMRI response, that is characteristic of the BOLD response in the primary olfactory cortex (i.e., a steep increase in the signal, peaking around 9 sec. after stimulus presentation)[6,7]. A late component (sustained response) was also modeled for the olfaction, motor and visual imaging data. Effects were thresholded to p $\leq$0 .05 map-wise.

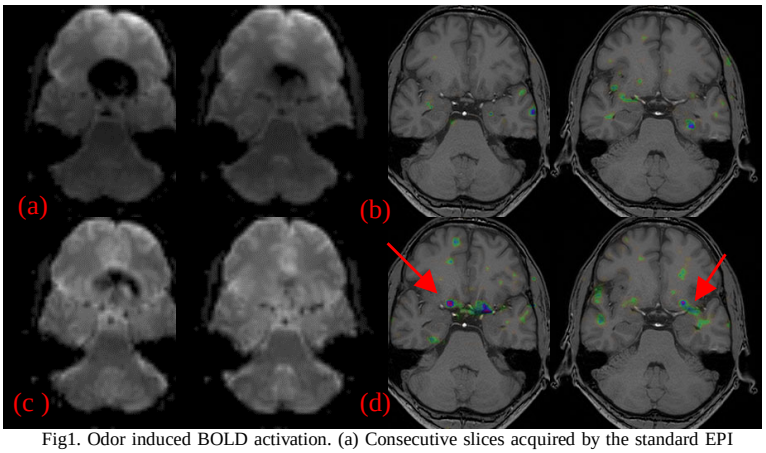

Fig1. Odor induced BOLD activation. (a) Consecutive slices acquired by the standard EPI sequences and (b) the same anatomical slices with overlaid activation. (c) the same slices as shown in (a) acquired by the optimized EPI SENSE sequence, with (d) overlaid activation.

Results As illustrated in fig. 1a and 1c, the optimized sequence with SENSE at 1.5T significantly recovered signal from the Orbitofrontal/Medial Temporal regions (fig.1c). Moreover, as illustrated by the arrows in fig. 1d, voxel-wise T-tests showed significant odor induced activation ($p<0.05$) in the recovered areas. As shown in fig. 2a, voxel-wise T-tests showed significant activation ($p<0.05$) in response to visual stimulation in visual cortex for both the standard and optimized sequences. In posterior regions, the BOLD sensitivity decrease was found to be less than 10%. Similar findings were observed for motor stimulation.

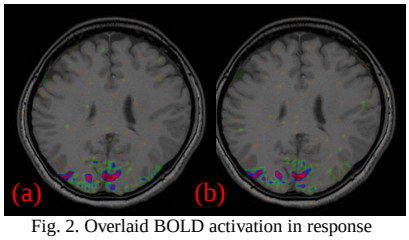

Fig. 2. Overlaid BOLD activation in response to visual stimulation in primary visual cortex. (a) standard and (b) optimized sequence

Conclusion These results replicate the findings of Deichmann and colleagues [2] at 1.5T using SENSE. Importantly, these findings show that signal recovery at the base of the brain can also increase BOLD sensitivity in these regions, without seriously diminishing activation in areas unaffected by susceptibility artifacts. Together these findings suggest that this optimized pulse sequence can be used to effectively investigate whole brain activation patterns. A unique contribution of the current study is the use of this optimized pulse sequence in combination with SENSE. Using SENSE can improve SNR up to 40% if the multiple coil array is not used to reduce acquisition time. Additional improvements in SNR and signal recovery may be obtainable when using the proposed optimized pulse sequence with SENSE at 3T to acquire images with higher in-plane and through-plan spatial resolution.

References . **1**. Wu LZ et al., MRM 48:312,2002. **2**. Deichmann R et al., NeuroImage, 2003. **3**. Gottfried, JA & Dolan RJ, Neuron, 39:375, 2003. **4**. Pruessmann KP et al., Medica MUNDI 44/2, 2000. **5**. Lorig et al., Behav Res Methods Instrum Comput, 31: 370, 1999. **6**. Sobel N et al., J Neurophysiol, 83(1):537, 2000. **7**. Poellinger A et al., Neuroimage, 13(4):547, 2001.