Sub-Millimeter Conventional fMRI at 3T With Dense, Shape-Optimized 32-Channel Posterior Head Coil

Boris Keil[1], Filip Grigorov[2], Andre J van der Kouwe[1], Lawrence L Wald[1,3], and Reza Farivar[2]

[1]A. A. Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Charlestown, MA, United States, [2]McGill Vision Research Unit, McGill University, Montreal, QC, Canada, [3]Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA, United States

Purpose: Visual function occupies the largest portion of the human cerebral cortex, but the functional units of the visual system can only be distinguished with very high resolution *in vivo* (e.g., ocular dominance columns [1]). *In vivo* measurements of these features in the human have thus far been limited to ultra-high fields (7T). High-resolution fMRI is limited by BOLD contrast and image SNR. While BOLD contrast is stronger at 7T, the image SNR difference between 3T and 7T can be mitigated by design-optimized phased-array RF coils. Here we tested whether a shape-optimized phased array coil with dense packing of 32 channels for only posterior-head imaging would result in the significant SNR gain needed to realize sub-millimeter conventional single-shot GE-EPI imaging at 3T.

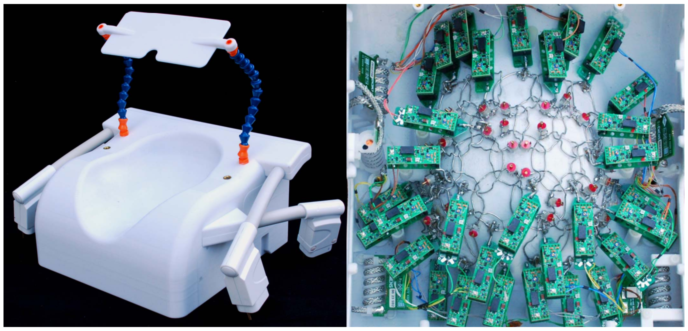

Fig1: Developed array coil (left), dense packing of 32ch, (right).

Material and Methods: We chose an open-faced form for the coil housing to increase working space in front of the eyes. The coil was shaped to a non-linear average of the head-neck T1-weighted images in the ICBM dataset, allowing for optimal posterior head coverage while providing good neck support, thereby minimizing the need for cushions (Fig 1a). Thirty-two ~40mm symmetric circuits were constructed from copper wire with matching and active detune circuits (Fig.1). Nearest neighbor decoupling was achieved by overlap (-15dB), with further and next-neighbor decoupling achieved by the preamp decoupling (-19dB) [2]. Data were acquired on a 3T scanner (TIM Trio, Siemens). SNR maps used 3mm isotropic PD-weighted FLASH images (TR/TE/α=300ms/15ms/20°). The array performance was tested in accelerated fMRI acquisitions using single-shot GE-EPI (0.75mm iso: 214x214 matrix, 25 slices, TE=31ms, TR=3s, R=4; PF=6/8). With slices oriented near-coronal, we captured 110 images of the posterior occipital cortex while a subject viewed a periodic stimulus (30s on, 30s off movie). Images were slice-time and motion-corrected, and temporally detrended but were *not* smoothed. Conventional GLM analysis was carried out using AFNI.

Results: The Q_U/Q_L-ratio of a sample loop was 2.8. The developed 32ch visual cortex coil exhibited a 2-fold SNR improvement compared to commercial whole-head 32ch coil (Fig.3). In addition, the small loop sizes provide an increased diffraction limit in parallel imaging encoding, empowering acceleration at 1.5 units higher with similar noise amplification compared to the commercial 32ch head coil. We were able to successfully map and measure visual function at 0.75mm isotropic resolutions at 3T, as depicted in Fig.2. Mapped activity was restricted to gray matter voxels, which could be clearly discerned at this resolution. Blood vessels could be readily dissociated from grey matter in these high-resolution EPI images. The raw time-course of a single active voxel is depicted in Fig.2. Despite the small voxel size (64x smaller than conventional 3mm voxels), high acceleration, and no spatial or temporal smoothing, we measured a robust modulation of activity driven by the visual stimulus.

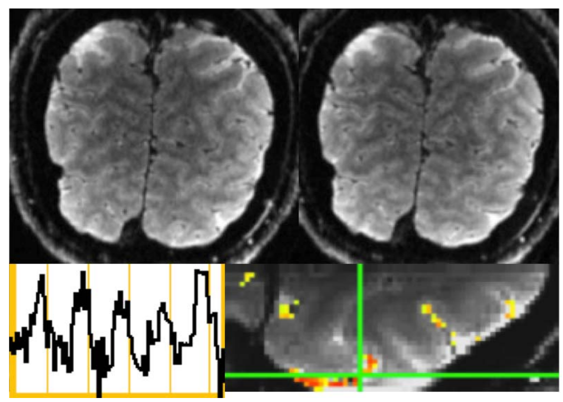

Fig2: Two 750um EPI slices of visual cortex (top) and activation pattern (bottom).

Discussion: We were able to overcome a number of technical challenges to designing and constructing a dense phased-array receive coil and demonstrated the capability of such a coil for mapping and measuring activity at the resolution of the functional units of the human visual cortex (i.e., <1mm). Array coils with small elements are technically challenging because the inter-element decoupling becomes more difficult and time-consuming as the element density increases. Maintaining a high Q_U/Q_L-ratio for such small loops is a challenge that we overcame by using an optimal helmet shape that is comfortable without additional padding, thereby minimizing the distance of the brain to the individual elements. The high achieved SNR allowed us to image at substantially higher resolution using a conventional GE-EPI sequence. It is likely that even greater improvements can be realized with accelerated segmented and/or multi-slice acquisitions. While we have yet to test the performance for diffusion imaging and other SNR-demanding applications, the results from the fMRI scans are promising and suggest similar gains to be made in other applications of interest to visual neuroscience.

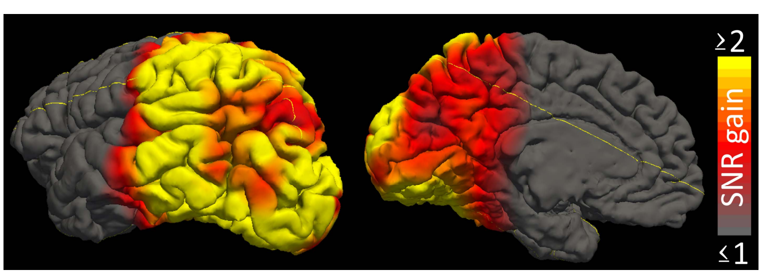

Fig3: Cortical SNR gain of developed coil comapared to a 32ch head coil.

Conclusion: A dense, form-optimized 32ch visual cortex array coil was constructed and compared to a commercial 32ch brain coil at 3T. The coil provides substantial gain in cortical SNR in accelerated imaging acquisitions. The coil allows for sub-millimeter functional imaging using a conventional sequence, and the resulting images empowered high-resolution mapping and measurement of visually-driven activity with minimal pre-processing.

References: [1] Adams, et al 2007. J. Neurosci, 27:10391-10403, [2] Roemer PB, et al. MRM 1990.