

High-Resolution Human Functional MRI: Feasibility and Specificity at High (3T) and Ultra-High (7T) Fields

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Introduction Robust high-resolution functional MRI below 1mm isotropic voxels promises to greatly expand the potential of human imaging to possibly enable the detection of columnar cortical activation patterns and the activation of specific subcortical nuclei. Effective imaging at high resolution depends on scanner field strength, acquisition capabilities enabling signal detection in cortical regions close to the surface as well as deep sources, imaging sequences reducing distortions and allowing for isotropic acquisition at high resolution, and appropriate processing methods. At high (3T) and ultra-high (7T) field MR imaging, there is a particular advantage for the use of multi-channel phased-array coils. Phased-array coils contain multiple small surface coil elements arranged in space so as to allow for extended brain coverage. Notably, the absence of RF body coil on current 7T systems requires the construction of detunable volume coils for efficient uniform transmit excitation [1,2,3]. Finally, for high-resolution imaging it is necessary to minimize distortions without compromising signal-to-noise ratio. Recently, parallel imaging methods have been used effectively to overcome these challenges. In particular, an extension of segmented EPI [4] to a 3D stack-of-segmented EPI sequence was developed [5], allowing for rapid acquisition of 3D volume. The present study demonstrates the feasibility of high (3T) and ultra-high (7T) field strength, multi-channel phased-array imaging of fine cortical architecture.

Methods Healthy human participants were studied using a flickering (7.5hz) checkerboard consisting of a partial-field (wedge-shaped) stimuli. This paradigm allowed for selective stimulation of topographically-specific portions within early visual areas. Imaging was performed using a Siemens Trio 3T system with gradient performance of 40 mT/m and 200 mT/m/s, and a MagneX Scientific, Siemens and MGH built 7T system with a head gradient set capable of 100mT/m and 800mT/m/s. On the 3T system, the signal was received with a standard Siemens 12-channel phased-array TIM coil or an in house 32-channel phased array coil, and on the 7T system, the signal was received with an 8- or 32-channel phased array coil (Fig. 1). On the 7T, excitation was achieved with a detunable birdcage transmit coil tuned for each subject to ensure a good power match. Blood-oxygenated-level dependent (BOLD) sensitive EPI sequences included: standard 2D EPI sequence (3T), standard 2D sequence (7T) and custom 3D multishot EPI sequence (7T). Transverse volumes were acquired at isotropic resolutions of 1, 2, and 4 mm every 5.4 sec.

Results and Discussion At 3T, multi-channel phased-array coils allow the detection of signals and corresponding functional topography at 1mm³. A particular advantage is seen with the use of 32-channel coils enabling the reliable detection of signals, suggesting that it significantly improves signal-to-noise ratio (Fig. 2). Retinotopically-specific activation patterns are clearly evident suggesting contributions from small, locally regulated vasculature. At 7T, the functional topography of occipital cortex can be seen at both 1mm³ and 2mm³, though 2D EPI suffers from increased distortions relative to the 3T system. Distortions are significantly reduced with 3D stack-of-segmented EPI, without loss of sensitivity to functional topography between the 2D and 3D sequences (Fig. 3). Thus, while preserving the fine anatomical details, 3D stack-of-segmented EPI allows the detection of fine functional topography of the cortex. It will be important to determine in future studies the limits of functional resolution, which will likely be determined by both the ability to achieve high signal-to-noise at small acquisition resolutions and BOLD-contrast sensitivity in vasculature that is locally regulated. Thus, across systems, receiving coils, and resolutions, selective and specific activation was obtained with minimally-distorted BOLD-contrast imaging at 1mm isotropic resolution. However, two tradeoffs were required including an extended volume acquisition time (TR) and limited acquisition volume. We further provide two solutions to these tradeoffs based on sampling timepoints across trials and merging slab volumes across runs.

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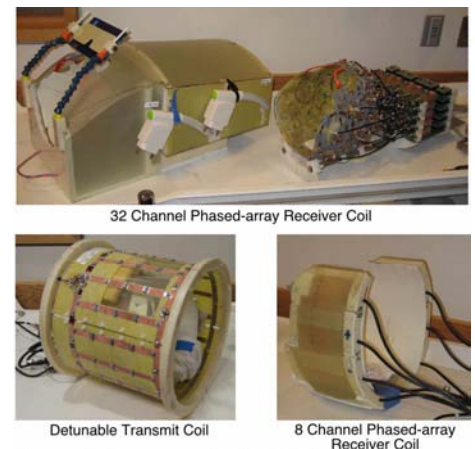


Figure 1. Custom-made (G. Wiggins) multi-element phased-array receiver coils with head-insert detunable transmit birdcage coil.

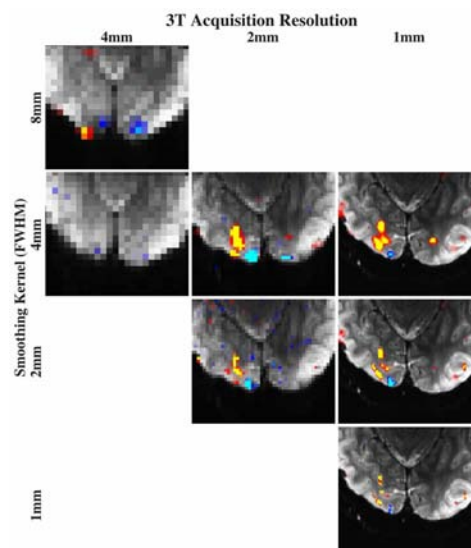


Figure 2. Statistical parametric map of the flickering checkerboard overlaid on 2D EPI acquired with 3T and 32-channel phased-array coil. Functional topography of the visual cortex can be observed at 1mm³.

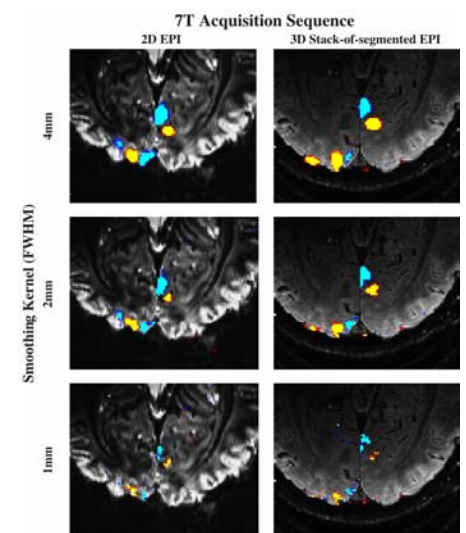


Figure 3. Statistical parametric map of the flickering checkerboard overlaid on 2D EPI and 3D EPI acquired with 7T and 8-channel phased-array coil. Spatial distortions are significantly reduced in the 3D EPI while functional topography is preserved.

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