Enhancing fMRI sensitivity at 7T with a modular 16-channel small element surface coil

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Introduction

The BOLD specificity and contrast to noise is enhanced at high fields allowing the delineation of neuronal activity in the human cortex at a finer scale than previously possible (1-3). Nevertheless the finer spatial or temporal scale of neurovascular coupling remains elusive or difficult to detect with fMRI even at 7T because the high spatial and temporal resolution required to explore these properties remain limited by signal-to-noise (SNR). However, multi element receiver arrays have been shown to improve SNR substantially as long as tissue losses remain dominant over coil losses. Recently Kumar et al (4) have shown that coil sizes for 7T may go down to 1 or 2 cm when positioned closely to the tissue to still improve SNR. To further enhance SNR at 7T we therefore developed a 16channel surface coil comprised of 1x2cm elliptic elements arranged in 4 flexible modules that can be positioned within 1mm from the human head. The temporal stability (tNSR) and BOLD sensitivity were compared to a standard 16-channel head coil for a BOLD acquisition using a visual task.

Materials and methods

16-channel surface coil: To achieve high SNR we designed and developed a modular multipurpose 16-channel receive only setup, consisting of 4 independent modules of 4 coils that can be placed individually on top of the region of interest (Figure 1). Each module has an outer dimension of 2.5 by 7.5 cm and is flexible as to remain in close proximity to the head. This small size leaves space to place multiple modules next to each other, and makes it possible to load all coil-elements properly. Each array consisted of four 1cm by 2cm coil-elements of elliptical shape, which were inductively decoupled by partial overlap between the adjacent elements. As the elements were strongly coupled to the tissue, no additional preamplifier decoupling circuitry was included. All elements are detunable and can be used in combination with high power transmit fields. The complete setup is interfaced via a 16-channel receive only box of the 7T scanner (Philips, Cleveland, USA).

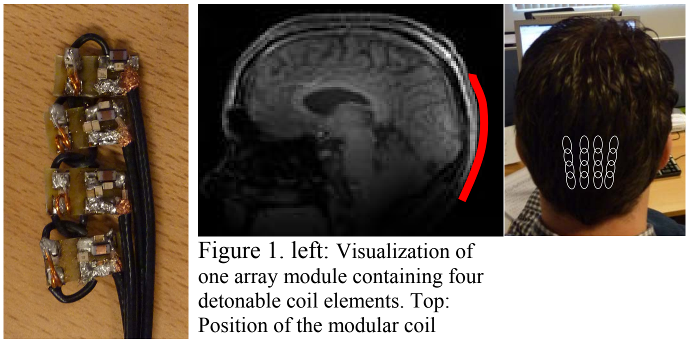

Figure 1. left: Visualization of one array module containing four detonable coil elements. Top: Position of the modular coil

Imaging: Scanning was performed on a 7T Philips scanner using a volume transmit coil, and for signal reception: 1) the custom-build 16channel surface coil, and 2) a 16-channel head coil (Nova Medical). Data were acquired using a single-shot GE-EPI acquisition with TR/TE=440/27ms, FA=60°, FOV=150×120 mm^2, and 3 coronal slices prescribed in the posterior part of the visual cortex. The SENSE factor was 3.5 and 2.3 for the custom and standard coils respectively. 3rd order image-based shimming was applied over the volume of interest using an in-house developed algorithm. Scans consisted of a 60s rest period followed by a 79s block-based design with off/on periods of 15.8/15.8s (uniform gray screen / 8Hz reversing checkerboard). Stimuli were presented via back-projection onto a screen mounted on the volume coil that was visible through mirrors. Subjects were secured in place using foam pads. Data were 2D realigned, corrected for linear trends, high pass filtered (cut-off : 1/31.6 Hz.), and corrected for slice timing. The tNSR was computed from the rest periods as the mean temporal standard deviation divided by the mean signal intensity over time. Active voxels were identified with regression of the stimulus waveform convolved with the canonical hemodynamic response. Activation maps were produced by selecting the largest significant cluster of voxels with a P threshold = 0.05, and Z threshold=3.5. G-factor maps were also reconstructed.

Results

S12 coupling was less than -15dB between all 16 coil elements of the surface array. In addition, G-factor maps of this setup do not exceed 1% for a SENSE acceleration factor of 3.5, while the standard 16 channel head coil has G-factors up to 30% for an acceleration factor of 2.3 (Figure 2A). The gain in sensitivity can be particularly appreciated in the improved tNSR (Fig. 2B) as well in the activation maps (2C) comparing the results for two subjects scanned with the custom-build as compared to the standard 16-channel coil.

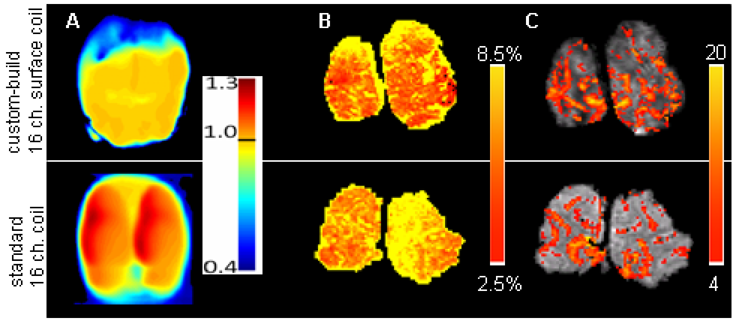

Figure 2. Comparison between custom-build 16 channel surface coil (top; subject 1) and standard 16 channel head coil (bottom; subject 2), for 1 slice. A. G-factor map, B: TSNR. C: Z-statistic activation map overlaid on the mean time course intensity image.

Discussion and Conclusion

We have shown that a surface array can be designed consisting of the theoretical smallest useful element dimension to enhance SNR at 7T. Making this array flexible in two dimensions allowed full coupling to the tissue, thereby excluding substantial crosstalk between elements even without preamplifier decoupling circuits. Results suggest that this surface array can be used with high resolution fMRI to improve sensitivity as compared to conventional receiver arrays.

References: 1) Yacoub et al, MRM 45:588–594, 2001. 2) Shmuel et al, NeuroImage 35: 539–552, 2007. 3) Yacoub et al. NeuroImage 37;1161–1177, 2007. 4) Kumar et al MRM 61: 1201-1209, 2009.