Improved BOLD Detection in the Working Memory Network using a 32 channel Phased Array Head Coil

S. Arnold[1], S. Whitfield-Gabrieli[2], S. Shannon[1], J. Gabrieli[2], and C. Triantafyllou[1,3]

[1]A.A. Martinos Imaging Center, McGovern Institute for Brain Research, MIT, Cambridge, MA, United States, [2]Department of Brain and Cognitive Sciences, MIT, Cambridge, MA, United States, [3]A.A. Martinos Center for Biomedical Imaging, Department of Radiology, MGH, Charlestown, MA, United States

Introduction: Low spatial resolution, because of its difficulty to reliably identify precise locations of blood oxygenation level dependent (BOLD) activity, is one of the current limitations in functional MRI (fMRI). The problem is augmented by susceptibility-related signal loss and partial volume effects in activated areas. Furthermore, sensitivity of fMRI is restricted by signal fluctuations due to physiological processes in the brain. Previous studies [1] have shown that this source of variance is proportional to the signal strength; therefore as the signal increases, either from higher field strengths, the use of improved array coils, or bigger voxel volume, only modest increase in the fMRI time-series signal-to-noise ratio (SNR) is achieved. The importance of translating the improved detection sensitivity into other desirable directions such as increased spatial resolution [1, 2] has been reported previously [3] with an fMRI task, but only with 16-channel head coil. The aim of the present study was to evaluate if significant reduction in voxel size in combination with the additive sensitivity of the 32-channel head coil would allow the identification of the working memory (WM) network using the n-back task, one of the most popular paradigms for functional neuroimaging studies of WM.

Methods: Eighteen normal right-handed subjects (9 males) were imaged using a 3T Siemens MAGNETOM Trio, a TIM System (Siemens Healthcare, Erlangen, Germany) and the product 12- and 32-channel head coils. 3D high resolution T1-weighted structural scan was acquired using an MP-RAGE sequence with voxel size = 1.3x1x1.3 mm^3, flip angle (FA) = 7°, TE=3.39 ms, TI=1100 ms, and TR=2530 ms. Functional BOLD measurements were obtained using a single-shot, gradient echo EPI sequence with TR/TE/FA=2000 ms/30 ms/90°. Thirty-two interleaved 3 mm thick slices were acquired (AC-PC orientation) with inter-slice gap of 0.3 mm and two different in-plane resolutions (a) 3x3 mm^2 (LRES) and (b) 1.5x1.5 mm^2 (HRES). Subjects performed a sequential letter, visual 2back WM task and a simple vigilance control task (the Continuous Performance Test "X" Task, or "CPT-X"). All stimuli were sequences of white uppercase letters on a black background, presented centrally (200 ms duration, 1800 ms inter-stimulus interval) in pseudo-random order. Each task was performed during two 5.6 minute scan sessions. Each scan consisted of six task blocks and six resting (display of fixation cross) blocks; the two tasks were presented in a blocked design (A-B-A-B-A-B), with three 32 second blocks of the CPT-X task (condition "A"), alternating with three 32 second blocks of the 2back task (condition "B"). Each block of task was preceded by a 20 second block of fixation, providing a pre-stimulus baseline and recovery period for the hemodynamic response in between the task blocks, followed by a 4 second period of visual task instructions. Subjects were instructed to respond as fast as they can to every stimulus using 2 button boxes, with one button used to signal targets and one used to signal non-targets. To perform the CPT-X (0back) task, subjects were instructed to identify the target letter "X," and identify all other letter stimuli as non-targets. To perform the 2back task, subjects were instructed to identify a target as any letter that was identical to the one that preceded it two stimulus trials back and identify all other letters as non-targets. In order to ensure that the repetition of recent letters could not be used as a cue to identify 2back targets, the blocks contained an equal number (3, 4 or 5) of "1backs" and "3backs" (letters identical to the letter that preceded it 1 trial back and 3 trials back respectively). The number of 1backs, 2backs, and 3backs were kept consistent in the 0back blocks as well. 16 letters were presented per block; 25% of the letters presented were "X"s in all the task blocks. Thus, the total number of targets and non-targets for any given scan was kept the same. Each subject performed two versions of the task at each resolution, and was scanned with two different coils (12- and 32-channel). To avoid any possible bias, task version, coil type and in-plane resolution were counterbalanced across sessions and subjects. Data analysis was carried out in SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK). EPI time-series were realigned, normalized and spatially smoothed with 5x5x5 and 3x3x5 Gaussian kernels for LRES and HRES respectively. The motion parameters were included as regressors in the design matrix. Activation maps (*2back>0back* contrast) were estimated for each subject using the general linear model with fixed-effects analysis. These contrast images were then compared statistically with second level analysis, by using the paired t-test (*32Ch >12Ch* and *12Ch >32Ch* contrasts) and one sample t-tests ($32Ch_{HRES}$, $12Ch_{HRES}$, $32Ch_{LRES}$, and $12Ch_{LRES}$ data sets) for quantitative evaluation.

Results: Paired t-test gave the following: (a) on HRES data set, the WM network, in agreement with previous reports [4], consisting of (i) bilateral and medial posterior parietal cortex, including precuneus and inferior parietal lobule, IPL (approximate BA7,40); (ii) anterior cingulate (BA32); and (iii) bilateral dorsolateral prefrontal cortex, DLPFC (BA9,46) were significantly active in 32Ch coil compared to the 12Ch coil (Fig. 1) with (false-discovery rate (FDR) corrected *p*-values at cluster level = 0.00001, 0.01, 0.009 for IPL, BA32 and DLPFC respectively); (b) on LRES data set, whole brain analysis did not reveal any regions for 32Ch coil which were significantly more active compared to the 12Ch coil; (c) WM network was not active in *12Ch >32Ch* contrast for both HRES and LRES data sets. One sample t-tests on the LRES data sets did not show BA32 activation (Fig. 2), but was significantly more in 32Ch HRES data set (t_{max}=7.44) compared to the 12Ch HRES data set (t_{max}=4.96).

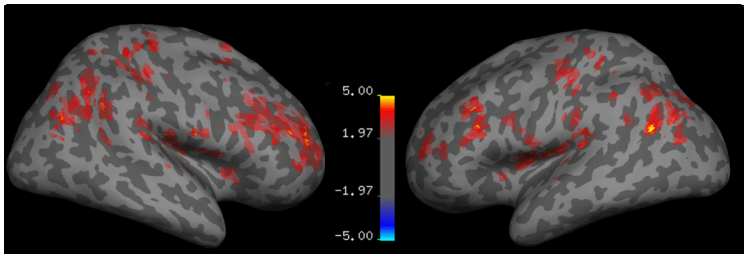

Figure 1: A surface representation of the SPM activation maps from paired t-test (N=18, p_{unc}=0.01, k=25) of HRES data set (*32Ch>12Ch* contrast) showing the WM network in the right and left hemispheres of the brain. The opposite contrast (*12Ch>32Ch*) did not reveal the WM network.

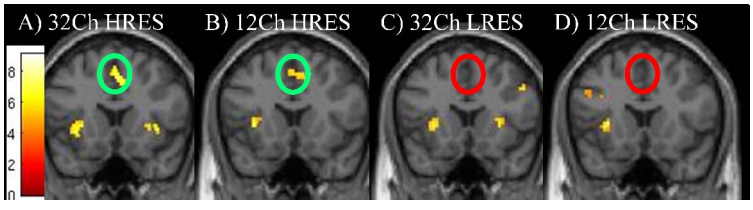

Figure 2: T-statistics (*2back>0back*) overlaid on T1-weighted structural scan from one sample t-test (N=18, p_{unc}=0.0001, k=25). BA32 activation (green oval) in 32Ch HRES data set (A) is significantly more (*p*=0.01, FDR corrected) than that of 12Ch HRES data set (B), while no activation was detected on the LRES data set, shown with red ovals in (C) and (D) for 32Ch and 12Ch coils respectively.

Conclusions: We have demonstrated that activation for the n-back task is significantly more with 32Ch coil compared to the 12Ch coil in the HRES data sets. In addition, the higher sensitivity of the 32Ch array translates directly into improved detection capability for BA32 activation, which was not detectable even at a group level in the LRES data set. Our evaluations suggest that when 12Ch and 32Ch phased arrays are used at 3T, the increased image SNR offered by arrays, produces the greatest benefit for fMRI experiments for medium to small voxel volumes. Therefore, using a combination of 32Ch coil and high resolution would be the preferable way to improve spatial accuracy in fMRI example in the WM network.

References: [1] Triantafyllou C et al, NeuroImage 2005; 26:243-250. [2] Triantafyllou C et al, Human Brain Mapping, 15th Annual Meeting, San Francisco, 2009. [3] Bellgowan PS et al, Neuroimage 2006; 29:1244-1251. [4] Owen et al, HBM 2005; 25:46-59.