Scan Time Reduction in fMRI using a 32 channel Phased Array Receive Coil

C. Triantafyllou[1,2], S. Arnold[1], S. Shannon[1], J. Gabrieli[3], and S. Whitfield-Gabrieli[3]
[1]A.A. Martinos Imaging Center, McGovern Institute for Brain Research, MIT, Cambridge, MA, United States, [2]A.A. Martinos Center for Biomedical Imaging, Department of Radiology, MGH, Charlestown, MA, United States, [3]Department of Brain and Cognitive Sciences, MIT, Cambridge, MA, United States

Introduction: In functional MRI (fMRI) studies, events/blocks are repeated several times so that task related activations are detected more reliably. This often leads to long experiments inducing subject fatigue and/or head motion, the levels of which may confound the results [1]. Moreover, such long experiments might not be feasible on specific subject populations. Typically, reduction in scan time is possible only at the expense of signal-to-noise ratio (SNR), but not necessarily if one could capitalize on the increased sensitivity afforded by high magnetic field strength or parallel multiple channel phased arrays in the high resolution regime [2,3]. The aim of the present study was to evaluate if significant reduction in acquisition time can be achieved by taking advantage of the additive sensitivity of the 32-channel head coil. The working memory (WM) n-back task was chosen for this purpose because it is one of the well studied networks [4]. Our findings demonstrate that activation for the n-back task is significantly more with two-thirds of the 32Ch data set compared to the 12Ch data set.

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, TR/TE/TI/FA=2530 ms/3.39 ms/1100 ms/7°. Functional data were obtained using a single-shot, gradient echo EPI sequence with TR/TE/FA=2000 ms/30 ms/90°. Thirty-two interleaved slices were acquired (AC-PC orientation) with inter-slice gap of 0.3 mm, voxel size = 1.5x1.5x3 mm^3. 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). Each subject performed two versions of the task, and was scanned with both 12- and 32-channel coils. To avoid any possible bias, task version and coil type 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 a 3x3x5 mm^3 Gaussian kernel. Activation maps (*2back>0back* contrast) were calculated for each subject using the general linear model with fixed-effect analysis. The motion parameters were included as regressors in both 12Ch and 32Ch data sets. The final design matrix for the 32Ch data set was decided in a couple of analysis iterations. First, the contrast images of the full data sets were compared with second level analysis, by using the paired t-test ($32Ch_{full} > 12Ch_{full}$ and $12Ch_{full} > 32Ch_{full}$ contrasts) and tested for statistical significance. This revealed the WM network only in the $32Ch_{full} > 12Ch_{full}$ contrast as expected. Then, half the data set from 32Ch coil was compared with full data set from 12Ch coil. Even though this revealed the WM network to be significantly active in $32Ch_{half} > 12Ch_{full}$ contrast (results not shown), the opposite contrast also revealed part of the WM network in a lesser extent. Thus the final design matrix of the 32Ch data set was chosen to have two-thirds of the total number-of-time points (N_{tp}) i.e., eight instead of twelve task blocks, to go through the model estimation. Beta-values for 2back and 0back conditions were extracted using the REX toolbox (http://web.mit.edu/swg/software.htm). Region of interests (ROIs) to be provided for these parameter estimates were identified based on a small volume correction (SVC) on the results of paired t-test ($32Ch_{two\text{-}thirds} > 12Ch_{full}$ *contrast*). Anatomically defined Brodmann areas (BA) for the WM network, as reported in previous studies [4], were used for this purpose using WFU pickatlas (http://www.nitrc.org/projects/wfu_pickatlas).

Results: Figure 1 shows the results of paired t-test in the $32Ch_{two\text{-}thirds} > 12Ch_{full}$ contrast. Compared to the full data set from 12Ch coil (N_{tp}=336), only the first two-thirds of the 32Ch data set (N_{tp}=224) were included in this comparison. There was significant activation in the WM network, 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 (BA9, 46) with family-wise-error corrected *p*-values at cluster level = 0.004, 0.0001, 0.05 for IPL, BA32 and BA9 respectively. Even though the 12Ch data set had 33% more time points compared to the 32Ch data set, $12Ch_{full} > 32Ch_{two\text{-}thirds}$ contrast did not reveal any regions of activation. Parameter estimates of two-thirds of 32Ch data set and full data set of 12Ch for IPL, BA32 and BA9 are shown in figure 2.

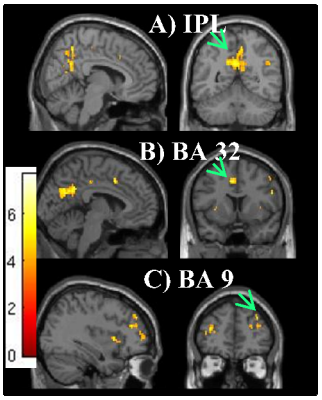

Figure 1: T-statistics overlaid on T1-weighted structural scan from paired t-test (N=18, p_{unc}=0.001, k=25) of HRES data set ($32Ch_{two\text{-}thirds} > 12Ch_{full}$ contrast). Activations in IPL, BA32 and BA9 are shown with green arrows in (A), (B) and (C) respectively. The opposite contrast ($12Ch_{full} > 32Ch_{two\text{-}thirds}$) did not reveal any regions of activation. The 32Ch data set that went into the analysis had 33% time-points lesser compared to the 12Ch data set.

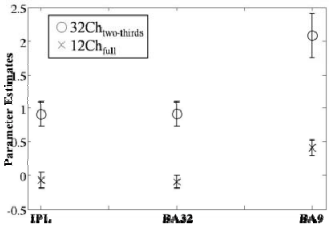

Figure 2: Parameter estimates were significantly higher from IPL, BA32 and BA9 in two-thirds of 32Ch data set (circles) compared to full data set from 12Ch (crosses).

Conclusions: We have demonstrated that activation for the n-back task is significantly more with two-thirds of the 32Ch data set compared to the 12Ch data set. This implies that in-addition to achieving 33% reduction in scanning time, the higher sensitivity of the 32Ch array provides improved detection capability for the WM network. This knowledge can be translated to power calculations [5] for group fMRI studies, thereby having a lesser sample size or preventing the collection of additional data that will have little impact on power. Furthermore, using a combination of 32Ch coil and high resolution would be the preferable way to go particularly in fMRI studies that would otherwise be impossible due to too long an acquisition time.

References: [1] Corbetta M et al, Science 1990; 4962:1556-1559. [2] Triantafyllou C et al, NeuroImage 2005; 26:243-250. [3] Triantafyllou C et al, Human Brain Mapping, 15th Annual Meeting, San Francisco, 2009. [4] Owen et al, HBM 2005; 25: 46-59. [5] Mumford JA and Nichols TE. Neuroimage 2008; 1:261-268.