Improved detection of functional connectivity MRI with 32-channel phased array head coil

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Introduction: Spontaneous low-frequency fluctuations (< .1 Hz) in the fMRI time-series exhibit specific networks of the human brain in the absence of a particular task [1-3]. Because of the task-independent nature of these studies, they are especially relevant for understanding brain's functionality/connectome for both healthy and clinical populations [4]. Although previous studies [5,6] have investigated the acquistion parameter space and methodology in functional connectivity MRI (fcMRI) using conventional (seed-based) and graph theory methods, the additive sensitivity from advances in multiple channel array coils remains yet to be explored in this domain. The ability of multiple channel arrays (e.g. 32-channel coil) in achieving scan time reduction and improved BOLD signal detection capability in the high resolution regime has been reported recently [7,8], but only while an fMRI task was performed. In this study, we compare functional connectivity mapping within and between the 32-channel and 12-channel head coils. In addition, we investigate if the 32-channel coil can extract and map spontaneous activity fluctuations more efficiently and robustly than 12-channel coil using connectivity and graph theory analyses. The comparisons indicate that although the 12-channel head coil shows robust correlations maps, the 32-channel phased array revealed increased detailed functional connectivity in the default mode network from smaller brain structures (e.g. parahippocampal gyrus) as well as increased global and local efficiency as demonstrated from graph theory analyses.

Methods: Sixteen subjects (7 males), age range 18-33 years (mean age: 25±5), were imaged using a 3T Siemens MAGNETOM Trio, a Tim System (Siemens Healthcare, Erlangen, Germany). Each subject scanned twice; with 2 different product receive head coils; a 12-channel (12Ch) and a 32-channel (32Ch) phased array. 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°. Six minute resting-state scans were acquired using a single-shot gradient echo EPI sequence. All subjects were asked to relax during the scan with their eyes closed. Sixty-seven interleaved slices were acquired (AC-PC orientation) with 2 mm^3 isotropic voxel size, TR/TE/FA=6000 ms/30 ms/90° and 62 time-points. Prior to connectivity analysis, data were realigned, slice-time corrected, normalized, spatially smoothed with an 8-mm kernel and temporally band-pass filtered (0.008 < f < 0.09). SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK) was used for data pre-processing. All the functional connectivity analyses were carried out using a Matlab based in-house developed toolbox CONN (http://www.nitrc.org/projects/conn/). Within-group analysis was performed on the whole brain. Seed regions for between-group comparisons were 10-mm-diameter spheres centered on previously published foci [9] including medial prefrontal cortex (MPFC), posterior cingulate/precuneus (PCC), and bilateral parietal cortices (LLP, RLP). Physiological and other spurious sources of noise were estimated using the Compcor method [10], and regressed out together with white matter, CSF and movement related (six parameters obtained by rigid body correction of head motion) covariates. Correlation maps were produced by extracting the residual BOLD time course from the seed, and computing Pearson's correlation coefficients between the seed time-course and the time-courses of all other voxels in the brain. Correlation coefficients were converted to normally distributed scores using Fischer's r-to-z transform to allow for second-level General Linear Model analyses. Finally, graph theory analysis was performed, also with the CONN toolbox, but with all the Brodmann areas (BA) as sources (88 different nodes) followed by modularity analysis [11]. The network parameters of interest were a) global efficiency, b) local efficiency, and c) cost.

Results: Voxel wise functional connectivity maps generated from the first set of analysis at the group level revealed two main findings (Fig.1). First, the connections in the left and right parahippocampal gyrus (BA 36) are absent in 12-channel data set. Second, connections within the left and right temporal cortices are significantly stronger ($p_{FDR-corr}$=0.007) in the 32-channel data set when compared to 12-channel data set. Analysis with graph-theory methods also generated two main findings. First, from analysis of global and local efficiency ($p_{FDR-corr}$<0.05) in the 32Ch > 12Ch contrast, only left and right anterior cingulate cortex (ACC) surpassed the top 10% connectivity (adjacency matrix threshold of 0.1) from the network of all ROIs. Second, from analysis of cost (modularity), only left and right ACC (BA33), left and right anterior entorhinal cortex (BA 34), left and right perirhinal cortex (BA35) and left and right BA 36 surpassed the same threshold ($p_{FDR-corr}$<0.05) in the 32Ch > 12Ch contrast (see figure 2). The opposite contrasts (12Ch > 32Ch) for both cases were not significant.

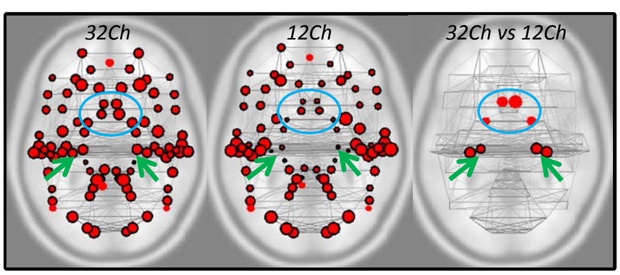

Figure 2: Graph visualization of the correlation matrices for analysis of cost for the top 10% functional connectivity ($p_{FDR-corr}$<0.05). 32Ch>12Ch comparison reveals BAs 33 and 34 (blue ovals) and BAs 35 and 36 (green arrows) indicating hyper/denser and hypo/sparser connectivity with 32Ch and 12Ch data sets respectively (n=16).

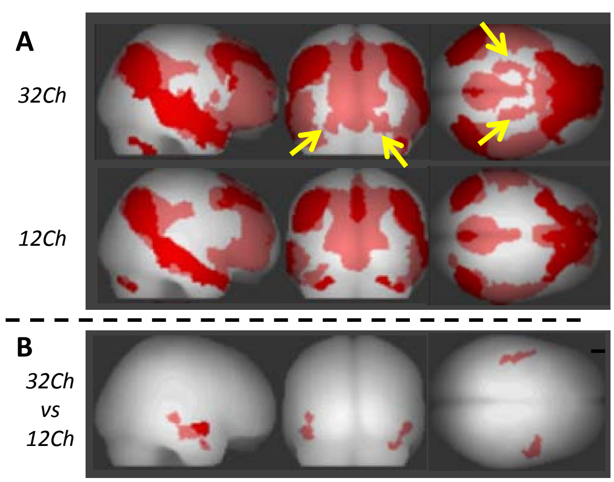

Figure 1: (A) Functional connectivity maps with default network during rest (averaged across 4 ROI seeds) from 32Ch and 12Ch coils (voxel and extent height thresholds are $p_{FDR-corr}$<0.001 and $p_{FWE-corr}$<0.001 respectively) at the group level (n=16). The default network with connections in the left and right parahippocampal gyrus are present only with 32Ch coil (yellow arrows). (B) Second-level analysis for 32Ch > 12Ch contrast; cluster level $p_{FDR-corr}$=0.007 for left and right temporal regions. No regions were significant in the 12Ch > 32Ch contrast.

Conclusions: Our findings from second level analysis demonstrate that the 32-channel coil offers specific advantages in terms of revealing functional connections in the default mode network (e.g. relatively smaller brain structures like parahippocampal gyrus) that were not identified by the 12-channel coil. Furthermore, graph theory analysis showed higher global and local efficiency of the network and better modularity, i.e., the degree to which a network is organized, for the 32-channel data set. The improved signal detection capability of the 32-channel coil and its higher sensitivity resulted in increased correlation strengths which could be extremely beneficial in connectivity studies, as a lesser sample size can be utilized for group level statistics thereby preventing additional data collection that will have little impact on power. Our evaluations suggest that using a 32-channel coil at 3T would be the preferable way to go in resting-state fcMRI studies.

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