High Resolution Functional Connectivity Mapping at 7T

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Introduction: Functional Connectivity MRI (fcMRI), based on correlations of spontaneous activity [1-3], has become an increasingly important tool to study brain networks. The improved sensitivity and resolution from advances in array coils and higher field strength allow a tradeoff between spatial resolution and partial volume dilution of the cortical activation with thermal and physiological noise components. These improvements in BOLD CNR potentially allow sub-structure in connectivity networks to be examined at a much higher spatial resolution than the 2-3mm scale (smoothed to 6-8mm) currently employed. The aim of this work is to determine the feasibility of studying resting state networks (RSN) with sub-millimeter resolution at a single subject level. We assess the quality of RSN connectivity maps at 7T by characterizing the effect of the voxel size across a range of isotropic resolutions with and without spatial smoothing. The comparisons indicate that robust connectivity can be detected at all resolutions, including the isotropic 500μm data, on a single subject, single 5min run, suggesting that fcMRI studies of small-scale networks are only limited by the biological point spread function of the underlying BOLD mechanism.

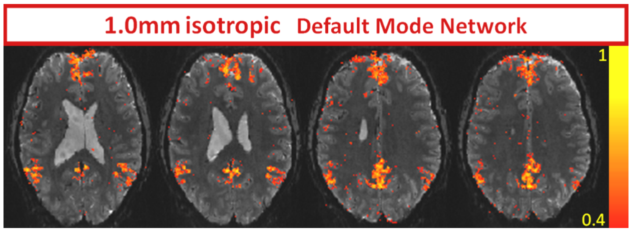

Figure 1: Single subject connectivity maps of the Default Mode Network at voxel size of 1mm isotropic and acquisition time of 5min, no smoothing was applied to the data.

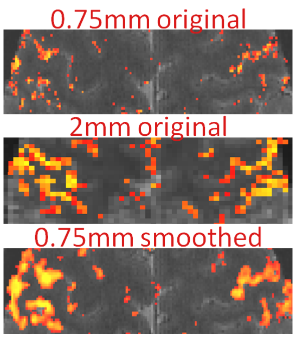

Figure 2: fcMRI maps of the motor network derived from the original unsmoothed 0.75 mm and 2mm isotropic data. For comparison 0.75mm data smoothed to 2mm also shown.

Methods: Ten subjects were scanned after obtaining IRB approval and written consent on a 7T Siemens scanner (Siemens Healthcare, Erlangen, Germany) with a 40cm diameter head AC84 gradient insert, using a 32-channel phased array receive-only head coil [4]. Connectivity within the motor network [1, 3] and the Default Mode Network (DMN) [2] were imaged. Resting-state time-series (no stimulus, subjects asked to relax) were obtained using a single-shot gradient echo EPI sequence with TR/flip = 5000ms/90° and 60 measurements at five isotropic spatial resolutions: 0.5mm, 0.75mm, 1mm, 1.5mm and 2mm. Parallel imaging with acceleration factors of 2, 3 or 4 was also employed (depending on the resolution used) to shorten the readout time and reduce geometrical distortions. A 3D high resolution T1-weighted MP-RAGE was also collected with voxel size of 1x1x1 mm^3, TR/TI/TE/flip = 2530ms/1100ms/3.48ms/7°, acceleration rate of 2. Data analysis was performed using FSL (FMRIB, Oxford, UK), and in-house developed Matlab software. Typical fMRI pre-processing was applied, including slice time, motion and drift correction as well as commonly used fcMRI preprocessing procedures; temporal filtering, estimation and regression of nuisance signals from motion parameters, white matter, and ventricles ROIs. Correlation maps were generated using the seed-based approach by computing the correlation between the 'seed' region and the time courses of all other voxels. The seed regions used, were the right primary motor cortex and the PCC (Post Cingulate Cortex) for the motor network and the Default Mode Network (DMN), respectively. Correlation maps were then overlaid on the EPI data in native space. To investigate the effect of spatial smoothing, 1, 2, and 3 voxel sized 2D Gaussian smoothing kernels were applied to the data.

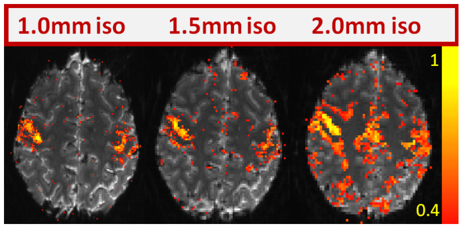

Figure 3: Correlation maps of the motor network on a single subject at 3 different isotropic resolutions when no smoothing was applied.

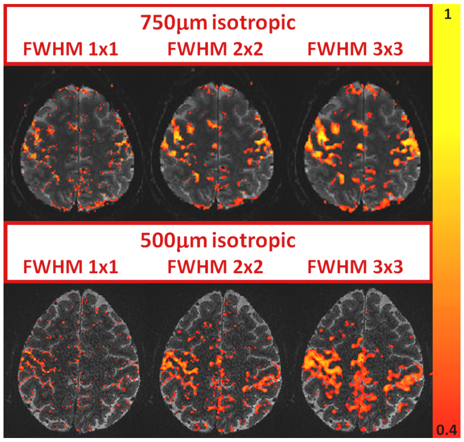

Figure 4: Connectivity maps derived from single shot gradient echo EPI at isotropic voxel size of 750 μm (top) and 500μm (bottom). From left to right connectivity maps generated when the data smoothed with Gaussian kernel of 1mm, 2mm, and 3mm respectively.

Results and Discussion: Fig. 1 shows the DMN from a single subject illustrating the correlation between the seed area (PCC) and the rest of the brain from 1mm isotropic acquisitions when no smoothing was applied. Fig. 2 shows the motor network from 0.75mm and 2mm isotropic data, as well as the 0.75mm when smoothed to 2mm. The original 0.75mm data show detailed gray matter localization. Fig. 3 shows the motor network in a single 5min acquisition for 3 different isotropic spatial resolutions (1mm, 1.5mm and 2mm), when no smoothing was applied. Fig. 4 shows examples of the correlation maps in the motor network from single subject data acquired with isotropic voxel size of 750μm (top) and 500μm (bottom). From left to right; correlation maps shown when smoothing was applied using Gaussian kernel of FWHM=1x1, FWHM=2x2, and FWHM=3x3, respectively. Higher spatial resolutions showed better gray matter localization, however the strength of the correlation between seed and target regions is weaker compared to lower resolution acquisitions when no smoothing was used, presumably from increased thermal noise.

Conclusion: High spatial resolution functional connectivity mapping was achievable in single subject, single run acquisitions at 7T using a 32-channel phased array receive coil. The results showed close adherence to the gray matter ribbon at higher resolution. Reduced ability to measure correlations at high spatial resolutions (where thermal noise dominates) was likely offset by improvements in partial voluming with white matter and CSF. Our results demonstrate that we were able to identify RSN using single-shot gradient echo EPI with acquisition time of 5min at all resolutions. The use of the 32-channel phased array enabled us to achieve highly accelerated acquisitions (e.g. at 500μm at acceleration rate of 4), which additionally facilitated reduced geometrical distortions that are greatly pronounced at ultra-high field strengths of 7T.

References: 1) Biswal B, et al., Magn Reson Med 1306 34(4):537-41, 1995 2) Fox MD and Raichle ME, Nat Rev Neurosci 8(9):700-11, 2007 3) Lowe M, et al., NeuroImage 7, 119–132, 2001 4) Keil B, et al., ISMRM 2010, Abst. 6960.