Simultaneous Measurement of Signal Fluctuations in GE and SE BOLD data during Resting State fMRI at 7T

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Introduction Spontaneous, low frequency fluctuations in connected networks have been identified in T_2*-weighted gradient-echo (GE) data [1], one such network is the default mode network (DMN) which comprises the medial prefrontal cortex, posterior cingulate, precuneus and parietal cortex [2]. GE-BOLD contrast has high sensitivity, but is sensitive to both large and small vessels. At 7T, the increased sensitivity of spin echo (SE) BOLD contrast can potentially be used to improve specificity to microvasculature, and SE-EPI is insensitive to signal-dropout due to through-slice dephasing. Here, we use a dual GE-SE-EPI sequence to identify functional connectivity maps from SE-BOLD data, and to assess correlated fluctuations in T_2*- and T_2-weighted images across multiple echo times in the DMN and other areas.

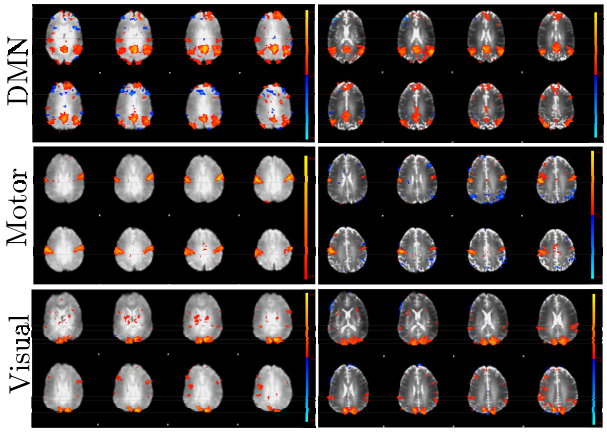

Figure 1: Networks identified from the dual GE/SE data using ICA. Left: GE BOLD data, Right: SE BOLD data. Positive correlations are displayed in red and negative correlations in blue.

Methods: *Data Acquisition:* Data was collected on a 7T Philips Achieva System using a volume transmit and 32-channel receive coil. A dual GE-SE-EPI sequence was implemented by modifying the SE-EPI sequence to acquire a GE-image prior to the 180° RF pulse, simultaneous acquisition of GE- and SE-EP images (temporal separation ~50ms, dependent on echo time). This sequence was used to collect 150 volumes of 15-slice GE/SE-EPI resting state fMRI data. Images were acquired at 3mm isotropic resolution, bandwidth 56.6 Hz/pixel with a TR of 2.5s (SENSE acceleration factor 2). The functional data acquisition was repeated four times collecting GE/SE images at echo time pairs of 17/60, 22/70, 27/80 and 32/90 ms. Inversion recovery (IR) images (10 inversion times from 100 – 2000 ms) were also collected for tissue segmentation. *Data Analysis*: The data were spatially smoothed using a 5mm FWHM kernel and inter- and intra- scan motion corrected. Independent component analysis (ICA) in MELODIC (FSL, Oxford, UK) was applied to the functional data sets to decompose the data into independent spatial maps. Independent component maps corresponding to the DMN were identified and a mask of the DMN created for both the GE and SE BOLD data using the ICA spatial maps generated from the data sets acquired at each echo time (voxels common to 3 of the 4 echo times). A common DMN mask from the GE DMN and SE DMN was also created by multiplication of the two binary masks. Data sets were de-drifted and high-pass temporal filtering applied. To assess the nature of the GE/SE signal fluctuations (i) a correlation analysis was performed between each GE/SE image pair and (ii) the fractional signal change in GE and SE BOLD data, given by the ratio $\delta R_2^*/\delta R_2$, was also calculated by using linear regression to find the gradient of the fractional signal change with TE for the SE and GE data (assuming BOLD related signal fluctuations dominate over thermal noise). The correlation coefficient and ratio were calculated on a voxelwise basis. Averages over the GE and SE DMN masks, common SE-GE mask, and non-specific grey matter (GM) and white matter (WM) regions, defined from the IR data, were also formed.

Mask	Corr. Coeff.	$\delta R_2^*/\delta R_2$
GE DMN	0.66 +/- 0.02	2.40 +/- 0.41
SE DMN	0.71 +/- 0.02	3.02 +/- 0.10
Com DMN	0.72 +/- 0.02	3.62 +/- 0.26
GM	0.55 +/- 0.03	1.91 +/- 0.30
WM	0.41 +/- 0.02	1.27 +/- 0.14

Table 1: Correlation coefficients in the GE and SE DMN combined masks, as well as the mask common to both of these and general WM and GM regions.

Results: The DMN was successfully identified using ICA in all subjects in the SE and GE BOLD data. Figure 1 displays example DMN spatial maps, and also motor and visual networks, identified from the IC analysis of GE and SE data. Table 1 shows the mean voxelwise correlation of GE and SE time-courses for each of the mask regions, along with the mean value of $\delta R_2^*/\delta R_2$. Correlation coefficients were significantly higher ($P < 0.05$) in all DMN masks than in general grey or white matter regions. The $\delta R_2^*/\delta R_2$ ratio was also significantly higher in the SE DMN and Com DMN masks than in the GM and WM regions. Figure 2 shows an example GE-SE correlation coefficient map, along with a map of the $\delta R_2^*/\delta R_2$ ratio together with the corresponding histogram of values. The maps indicate that the simultaneous signal fluctuations in SE and GE data are more strongly correlated in GM than WM, and that $\delta R_2^*/\delta R_2$ is also higher in GM.

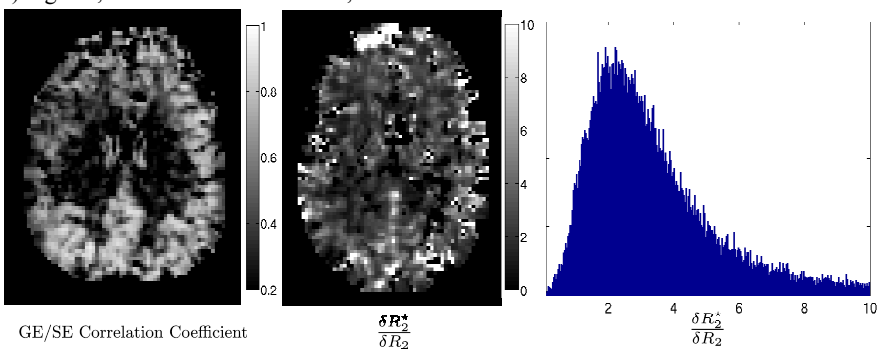

Figure 2: Left image: Voxelwise correlation coefficient between GE and SE data. Middle image: Image showing the ratio $\delta R_2^*/\delta R_2$ (found using linear regression). Right image: Histogram of $\delta R_2^*/\delta R_2$ values from data taken across the whole head.

Discussion: We have demonstrated that resting state functional networks can be identified using SE-BOLD contrast at 7T, despite the reduced sensitivity of the SE BOLD contrast [3]. The use of a dual GE/SE sequence allowed correlations between the GE and SE BOLD data to be assessed for functional networks, and fractional changes to be evaluated. The data in Table 1 indicate that SE and GE signal fluctuations are more strongly correlated in the DMN than in general grey or white matter. The ratio of $\delta R_2^*/\delta R_2$ was found to be 1.91 ±0.30 in the grey matter region, in good agreement with the value of ~2.1 found for task-induced changes in the motor cortex [3]. The ratio was found to be significantly higher in the SE and common DMN masks, this may be related to the presence of large draining veins in the GE DMN mask.

References: [1] Biswal, B et al. Magn Res Med 1995; 34:537-541 [2] Raichle, M. E., et al. (2001). PNAS 2001; 98:676-682 [3] Harmer et al 2011, NMR in Biomedicine, in press.