Characterization of Whole-brain Dynamic Connectivity Patterns using Simultaneous MultiSlice (SMS) Resting-State fMRI

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Purpose: The ability to decode and distinguish cognitive states from brain imaging data is a major goal of neuroscience[1,2]. Recent advancements in data acquisition and multiband imaging techniques have enabled whole-brain fMRI scanning at sub-second temporal resolution[3,4]. Taking advantage of powerful properties of this new acquisition technique, we probed the dynamic changes in whole-brain functional connectivity at rest within short periods of time (17.5 s) that would have not been possible using common fMRI acquisition techniques. Also we were able to characterize these dynamic changes into distinct connectivity states.

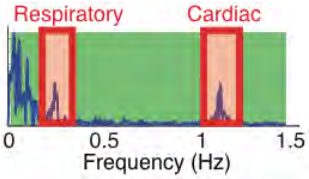

Figure 1. Frequency band used for the analysis. Red areas were filtered out.

Methods: Six healthy volunteers (36±15 years; range 25-62) were scanned at 3T (GE Discovery MR750) using a 32-channel head coil (NOVA Medical). Resting-state fMRI (rsfMRI) data were acquired using a Simultaneous MultiSlice (SMS) EPI with blipped CAIPI sequence[4] with TR/TE= 350/30 ms, multiband acceleration factor of 6, CAIPI FOV shift of 3, FOV= 22x22 cm^2, matrix size =70x70, number of slices = 30, slice thickness = 4 mm, scan duration 175s (500 volumes). EPI images were preprocessed and normalized to MNI atlas space. A high-pass filter was applied to remove low-frequency signal drifts (<0.01Hz) from the data. A low pass filter is often used in rsfMRI but was excluded here to retain potentially useful information in the higher frequency bands. Only respiratory and cardiac frequency bands were removed from the signal (Fig.1). For all subjects, whole-brain functional connectivity matrices were estimated from the Pearson correlation coefficient (r) between the time series of 236 putative functional areas[5] (Fig.2a) over a sliding window (duration:17.5 s, steps:7 s). Connectivity matrices from all subjects where then clustered into 5 states using the k-means algorithm with the correlation distance metric. The number of clusters was defined using the elbow method[6]. **Results**: Fig.2b shows evolution of the whole-brain functional connectivity matrix and its default mode network portion over time in one subject. Fig.2c shows graph representation of the defined cluster centers. In these graphs, the node size represents the summation of the connectivities to that node, and edges represent connections with |r|>0.5. Transitions between these functional connectivity states during the scan for all subjects are shown in Fig.2d. Distinct states of whole-brain functional connectivity were observed in all subjects. The average time spent in each state was 29.6±9.7 s.

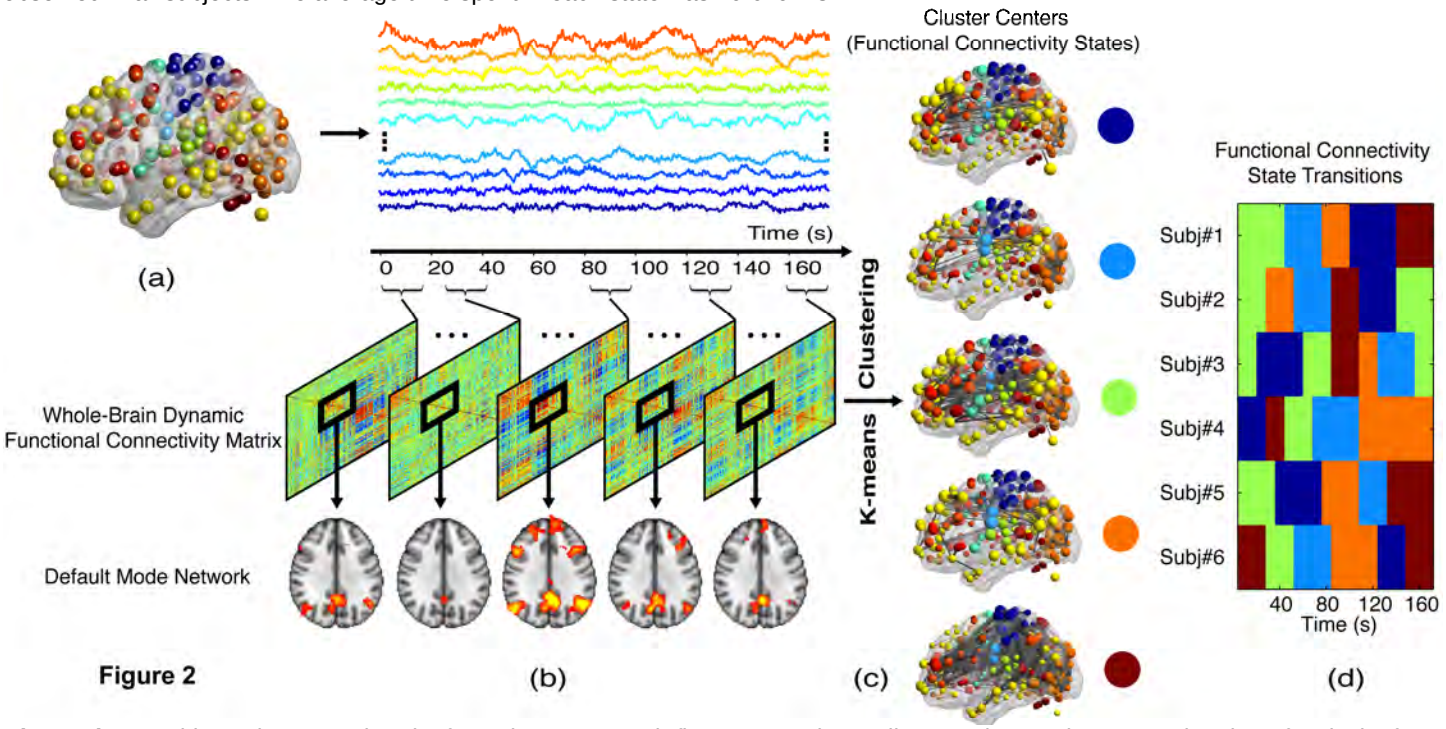

Figure 2

Discussion: In this study, we explored rsfMRI data on a much finer temporal sampling rate (350 ms) compared to that of typical rsfMRI experiments (>2s). Our results revealed that functional connectivity networks show dynamic patterns over short periods of time that are not apparent from stationary analysis. These results are consistent with other studies which have shown dynamic connectivity over longer periods of time[2,7,8]. Note that the short TR achievable with SMS imaging enabled the use of a wider frequency band (Fig.1), that significantly improved the quality of connectivity maps in very short windowed segments, which in turn, was essential for short-term dynamic rsfMRI analyses (e.g. the 17.5s default mode network maps shown in Fig.2b). SMS rsfMRI coupled with the analysis approach outlined here provides a valuable tool to study the dynamic associations between cognitive/behavioral states and rsfMRI data.

References: [1] Shirer et al. Cerebral Cortex, 2012. [2] Allen et al. Cerebral Cortex, 2012. [3] Feinberg et al. Plos One, 2010. [4] Setsompop et al. MRM 2012. [5] Power et al. Neuron, 2011. [6] Goutte et al. NeuroImage 1999. [7] Chang et al., NeuroImage, 2010. [8] Hutchison et al. NeuroImage, 2013.
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