Resting state networks detection, the importance of high temporal resolution: a comparison study between 2D-EPI, SMS 2D-EPI and 3D-EPI-CAIPI acquisitions

Mayur Narsude[1,2], Wietske van der Zwaag[1], Daniel Gallichan[1], Rolf Gruetter[1], and Jose Marques[2]
[1]CIBM, EPFL, Lausanne, Vaud, Switzerland, [2]University of Lausanne, Lausanne, Vaud, Switzerland

Target audience: Neuroscientists or physicists with an interest in high temporal resolution fMRI.

Purpose: Research from various groups has demonstrated that both functional connectivity research as well as task-driven fMRI benefit from improved statistics attainable through a higher sampling rate [1-3]. Parallel imaging (PI) in the slice-encoding direction is commonly used to increase temporal resolution in both 2D- as well as 3D-EPI sequences, the extent of which is limited by spatially varying noise amplification (the g-factor). 2D-CAIPIRINHA is known to reduce g-factors for 3D imaging for a given acceleration [4] and has been recently been demonstrated for 3D-EPI acquisitions [5]. In this study, we compare resting state fMRI of CAIPIRINHA enabled 3D-EPI (3D-EPI-CAIPI) [5] and simultaneous multi-slice blipped 2D-EPI (SMS-EPI) [6] relative to standard multi-slice 2D-EPI (2D-EPI).

Method: Six subjects (3 females, ave. age 26 years) were scanned on a 7T (Siemens, Germany) scanner with a 32Ch head Rx coil (Nova Medical Inc., USA). Common parameters: Transverse orientation, TE=26ms, in-plane matrix=106x106, 2x2x2mm^3, rBW=2358Hz/Pixel. Differences - 2D-EPI: TR_{volume}=2.92s, slices= 60, FA=60° (SAR restricted), Partial Parallel Acquisition (PPA)=2, volumes=102. SMS-EPI: TR_{volume}=1.08s, slices=61, FA=57° (α_{ernst}), PPA=2x3, PE shift-factor=3, VERSE factor:1.0, volumes=278. 3D-EPI-CAIPI: TR_{volume}=1.02s, partitions=60, FA=14° (α_{ernst}), PPA=2x3, CAIPI-Δ=1, volumes=294. Total scan time was kept constant at 5 minutes per run and the acquisition order of the 3 runs was randomized. Anatomical images were acquired using MP2RAGE sequence [7].

Datasets were motion corrected using MCFLIRT [8], high-pass filtered (<100s), smoothed (3mm FWHM), first co-registered to anatomical images, and subsequently to the MNI template. Resting state networks (RSNs) were identified via ICA using MELODIC [8].

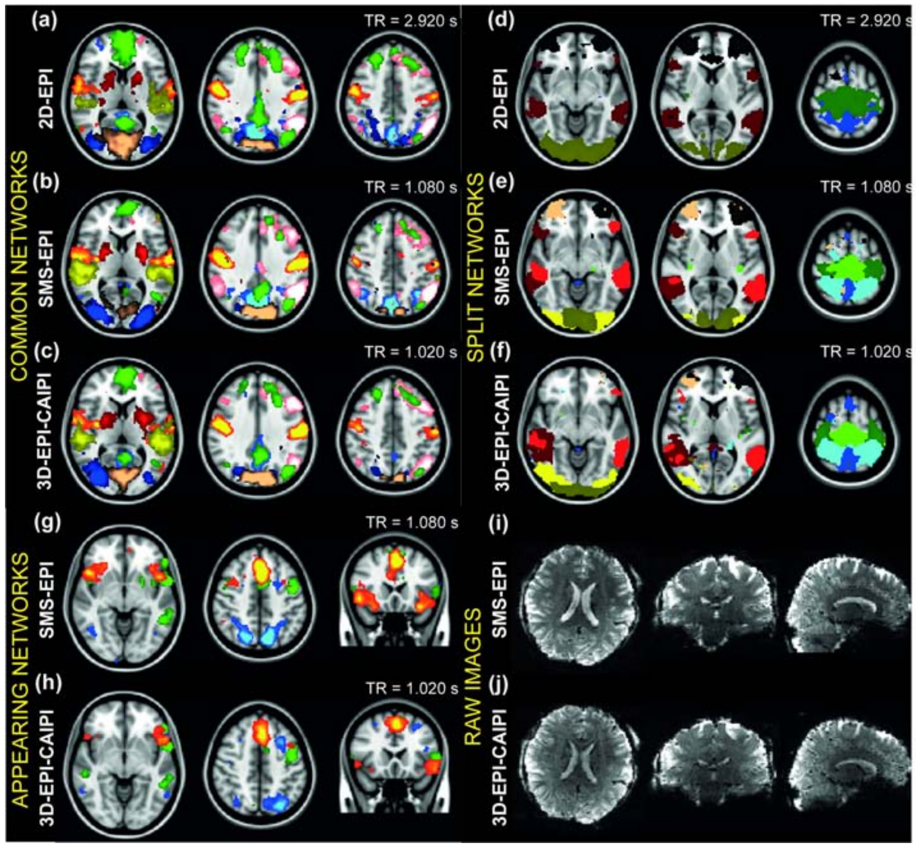

Figure 1: Resting state networks shown overlaid on the MNI template. Resting state networks were categorized as "common networks" (identifiable in all 3 acquisitions (i.e. 2D-EPI, SMS-EPI and 3D-EPI-CAIPI); "split networks" (a single network found in 2D-EPI which appears as multiple components in SMS-EPI and 3D-EPI-CAIPI); and "appearing networks" (identifiable in SMS-EPI and 3D-EPI-CAIPI, but not in 2D-EPI). See text for names of the networks identified. Example "raw images" for SMS-EPI and 3D-EPI-CAIPI are also shown.

Results: The slice-direction acceleration resulted in increased time points for SMS-EPI and 3D-EPI-CAIPI compared to 2D-EPI, and an improved statistical power in the RSN detection. With 3D-EPI-CAIPI, parallel acquisitions were achieved without any peak power or SAR penalty, unlike SMS-EPI in which the peak power of the multiband pulse scales with the square of the number of simultaneously excited slices, an effect which is only partially remedied by the short TR and thus relatively low α_{ernst}. The FA used for 3D-EPI-CAIPI was 14° implying ~19-fold reduction in the SAR compared to 2D-EPI which used a FA of 60° (SAR restricted) since SAR $\propto$ (FA)^2.

Figure 1(a-c): "common networks" which were found with all the three sequences: primary visual (brown), lateral visual (blue), default mode (green), sensory motor (red-yellow), basal ganglia (red), auditory (yellow-green), medial visual (blue-lightblue) and left lateral (pink). Figure 1(d-f): "split networks" that were found to be split across multiple ICs in the data sampled at higher temporal resolutions. The general visual network (Fig. 1d, olive green), found as a single component with the 2D-EPI was split across 2 different components (Fig. 1(e-f), olive green & yellow) for SMS-EPI and for 3D-EPI-CAIPI. Similarly the ventral stream (red & bright red), frontal pole (black & pink), primary motor (green & bright-green) and precuneus (blue & bright-blue) are a few other split networks shown. Figure 1(g-h): "appearing networks" (which were found only at higher temporal resolutions): task positive (blue-lightblue), salience (red-yellow) and language (green) networks.

Discussion and conclusion: The improvement in detection of RSNs with faster sampling is consistent with previous observations [1, 3]. Similar RSNs were detected in 3D-EPI-CAIPI and SMS-EPI, with both of these short TR_{volume} sequences detecting more RSNs than 2D-EPI, with some RSNs splitting into more components, making them more specific. Further investigation will be needed to assess if the splitting of the networks was due to the increased dimensionality for IC analysis (due to increased number of volumes) or a result of the higher sampling rates.

It should be noted that the image reconstruction pipelines used for the two datasets were different (higher order phase correction was used for SMS-EPI but not for 3D-EPI-CAIPI and the parallel imaging reconstruction was fundamentally different). Unlike SMS-EPI, 3D-EPI-CAIPI offers the possibility of using partial Fourier coverage on the slice encoding direction (for the sake of simplicity of the comparison this feature was not explored in this study). Given this limitation, both the resting state networks and the image quality (Fig. 1(i-j)) obtained with 3D-EPI-CAIPI and SMS were remarkably comparable.

Finally, 3D-EPI-CAIPI compared to SMS-based techniques uses reduced SAR and peak power deposition making it an ideal candidate for ultra-high field applications.

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