Whole brain fMRI in 370ms: exploring the benefits of high temporal resolution 3D-EPI-CAIPI

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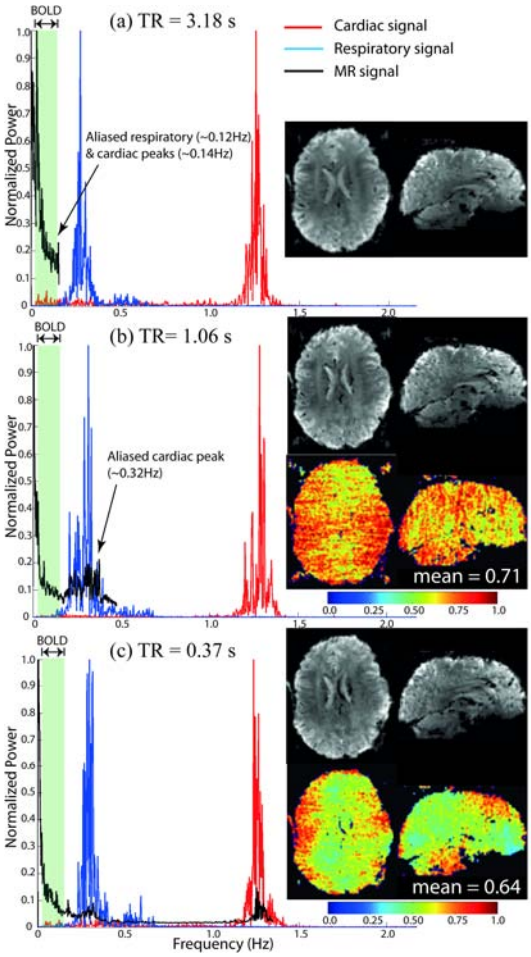

***Figure 1**: Power spectra of MR data at 3 different sampling rates along with those of respiratory and physiological signals. Two orthogonal image planes along with 1/g maps are shown in the inset for corresponding sampling rates. Expected aliased physiological signal peaks are indicated with arrows.*

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

Purpose: Controlled aliasing [1] with segmented 3D-EPI can be used to increase either temporal resolution [2] or in-plane spatial resolution [3]. The supported extent of under-sampling in parallel imaging depends largely on local g-factors. 2D-CAIPIRINHA helps restrict g-factors to a tolerable level by distributing k-space samples more evenly in 3D k-space [1], making effective use of coil sensitivity variations in the two phase-encoding directions.
In this study, controlled aliasing with 3D-EPI is used for high temporal resolution fMRI, demonstrating the ability of higher sampling rates acquisitions to filter out physiological signal fluctuations resulting in improved statistical power on the detection of resting state networks.

Method: All data was acquired on a 7T (Siemens, Germany) scanner with a 32Ch head Rx coil (Nova Medical Inc., USA). MR data was acquired using 3D-EPI-CAIPI at 3 different sampling rates while monitoring the respiratory and cardiac cycles. Common parameters: TR/TE=48/26ms, FA=13°, matrix size=106x106x60, 2x2x2mm^3, rBW=3144 Hz/Pixel and, when parallel imaging was performed, ACS_{data}=106x48x36 and $GRAPPA_{kernel}$=3x3. Remaining in parameters: TR_{volume}=3.18s: PPA=1x1, N_{vol}=94, R=1; TR_{volume}=1.06s: PPA=1x3(Δ=1), N_{vol}=283, R=3; TR_{volume}=0.371s: PPA=1x6(Δ=2), PF_z=6/8, volumes=808, R=8.
Two runs at each protocol were performed in a randomized order. An MP2RAGE anatomical was also acquired [4]. After motion-correction using MCFLIRT [5], power spectra for physiological signals and MR data was analyzed. All datasets were temporally low-pass filtered (f_c=0.14Hz) to filter out respiration and cardiac pulsation while keeping slow BOLD activity. Subsequently the datasets were temporally down-sampled to produce TR_{volume}=3.18s (94 volumes). All functional datasets were co-registered to the anatomical images and ICA was performed using MELODIC [5]. Resting state networks (RSNs) were identified visually. g-factor maps were calculated using 100 pseudo replicas[6].

Results: The power spectra of the physiological signals and whole brain averaged fMRI time courses are shown in Figure 1. The insets show examples of the whole-brain images acquired and 1/g maps. The image quality at all sampling rates was acceptable, with R_z=8 (TR=0.371s) resulting in only ~11% additional g-factor losses compared to R_z=3 (TR=1.06s). With the 3.18s TR, both the respiratory and cardiac peaks (observed at ~0.28Hz and ~1.26Hz respectively), were aliased into the BOLD frequency range (0.04Hz-0.13Hz, Fig.2, green band). With a TR=1.06s, only the cardiac peak was aliased whereas TR=0.371s was sufficient to sample both the physiological peaks well (MR signal power spectra -black- shows both respiratory and cardiac peaks and the BOLD baseline is significantly lower). Figure 3 shows six representative RSNs identified from ICA analysis of different datasets. The networks were found to have higher statistical significance using shorter TRs (larger colored areas). The mean temporal SNR per unit time value (calculated in 6 different ROIs in gray matter) for the 0.371s dataset was 37.35±1.25, which was ~62% and 26% higher than in the 3.18s (23.05±1.64) and 1.06s (29.66±1.62) datasets, respectively.

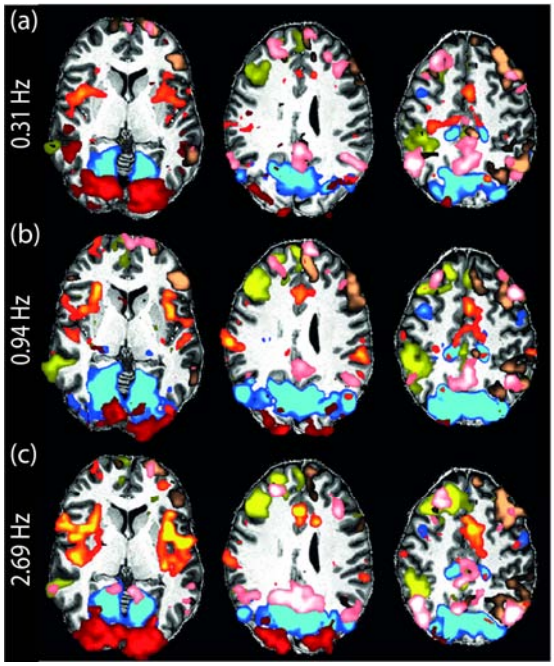

***Figure 2**: Six resting state networks from datasets acquired at 3 different sampling rates as indicated on the left of each panel. After low-pass filtering (f_c=0.14Hz) all datasets, 0.94Hz and 2.69Hz datasets were under-sampled to create effective sampling frequency of 0.31Hz each. All networks were applied a threshold from Z = 3 to 8.*

Discussion and conclusion: Use of 2D-CAIPIRINHA with 3D-EPI can exploit the coil sensitivity variations better, reducing g-factor noise in the reconstructed datasets and thus enabling higher net acceleration factors. An increased acceleration has a direct impact on the temporal resolution and temporal SNR achievable in fMRI [7] clearly out-weighing the relatively mild g-factor penalty. Higher temporal resolution enables better characterization of physiological signal fluctuations which can then be removed by: either low-pass filtering or via physiological noise reduction schemes [8-9]. The 8-fold acceleration demonstrated in this abstract, TR_{volume}=0.37 opens the door to the study of subtler temporal information with BOLD fMRI.

References: [1] Breuer, F.A. et al., Magn Reson Med, 2006. 55:p. 549-56; [2] Narsude, M.C. et al., ISMRM, 2013. [3] Poser, B.A. et al., ESMRMB, 2013.; [4] Marques, J.P. et al., NeuroImage, 2010. 49: p. 1271-81; [5] www.fmrib.ox.ac.uk/fsl [6] Robson, P.M. et al., Magn Reson Med, 2008. 60: p. 895; [7] van der Zwaag, W. et al., MRM, 2012. 67(2):344-52. [8] Bianciardi, M. et al., Neuroimage, 2009. 44(2) :448-54. [9] Glover, G.H. et al., MRM, 2000. 44(1):162-67.

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