PHYSIOLOGICAL AND SYSTEM-INDUCED FIELD FLUCTUATIONS IN EPI TIME SERIES IN VIVO

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Introduction: In functional MRI, stimulus-correlated changes in a voxel time series are analyzed to infer on activation patterns. The BOLD effect, as a measure for neural activity, induces the targeted changes in image intensity. However, image fluctuations can also be caused either by system-related or physiologically induced field fluctuations, such as breathing. In this work, we used concurrent magnetic field monitoring in-vivo to measure system and physiological fluctuations in the encoding fields of multiple EPI time series. Principal Component Analysis disentangled these fluctuations stemming from different sources. Furthermore, we assessed the Signal-to-Fluctuation-Noise-Ratio (SFNR) losses in the image time series due to these field fluctuations.

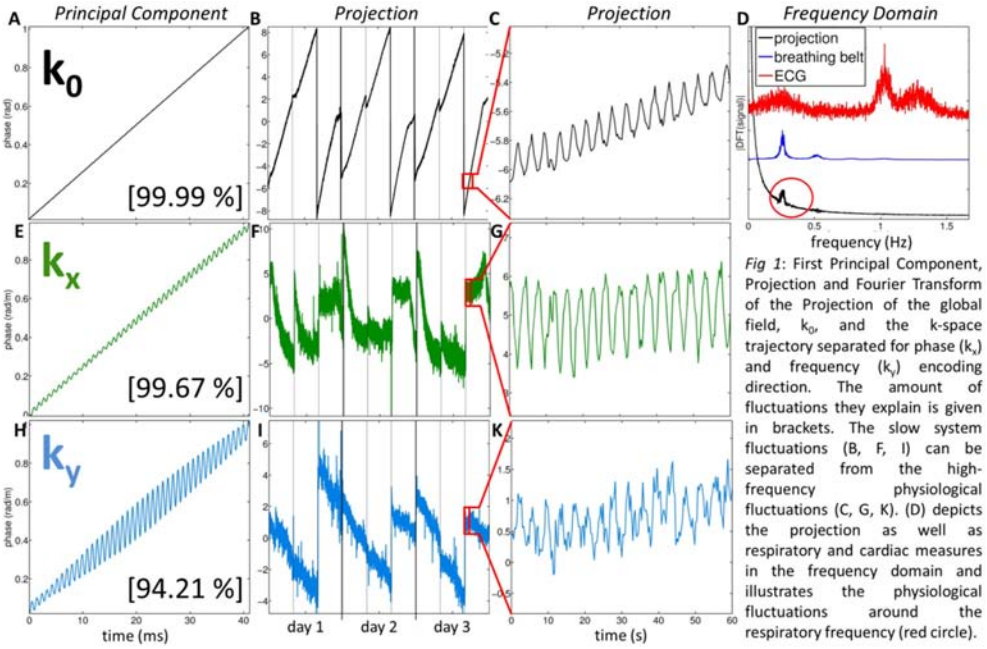

Fig 1: First Principal Component, Projection and Fourier Transform of the Projection of the global field, k_0, and the k-space trajectory separated for phase (k_x) and frequency (k_y) encoding direction. The amount of fluctuations they explain is given in brackets. The slow system fluctuations (B, F, I) can be separated from the high-frequency physiological fluctuations (C, G, K). (D) depicts the projection as well as respiratory and cardiac measures in the frequency domain and illustrates the physiological fluctuations around the respiratory frequency (red circle).

Methods: We acquired a typical fMRI protocol in vivo on 3 different days consisting of 3 EPI time series each. Every time series contained 400 scans (2.5 mm isotropic resolution, TR 3 s, readout duration 41.1 ms, 10 axial slices) and lasted 20 minutes. Data from the same healthy volunteer (BMI ≤ 20) was acquired on a Philips Achieva 3 T system with an 8-channel head coil and a concurrent magnetic field monitoring setup (12-channel T/R 19 F NMR probes) [1]. The probe phases measured with this setup were fitted to a spatial model of 2nd order spherical harmonics. The 0th order phase coefficient k_0 corresponds to the B_0-field modulation. The 1st order phase coefficients k_x and k_y are the k-space trajectory. We studied the fluctuations in k_0, k_x and k_y within the EPI time series using Principal Component Analysis (PCA) [2]. Herein, the Principal Components (PC) represent characteristic fluctuation patterns of the EPI readout. The projection of the phase coefficients on the PCs yield the magnitude of these characteristic fluctuation patterns over scans. We disentangled physiological from system fluctuations in k_0, k_x and k_y via the frequency band of physiological fluctuations (f_{min} = 0.15 Hz, f_{max} = 1.2 Hz) determined by independent peripheral measures (ECG, breathing belt). Each PCA projection was then split into its physiological fluctuation component (power within the frequency band) and its system fluctuation component (remaining spectral power). To retrieve reference image time series, we entered the measured phase coefficients, which include all fluctuations in k_0, k_x and k_y, in an iterative, gridding-based image reconstruction [3,4]. We also investigated the influence of system and physiological field fluctuations on image time series. To this end, we selectively removed field fluctuations of different order and origin, based on the filtered PCA projections, from the measured phase coefficients before reconstruction.

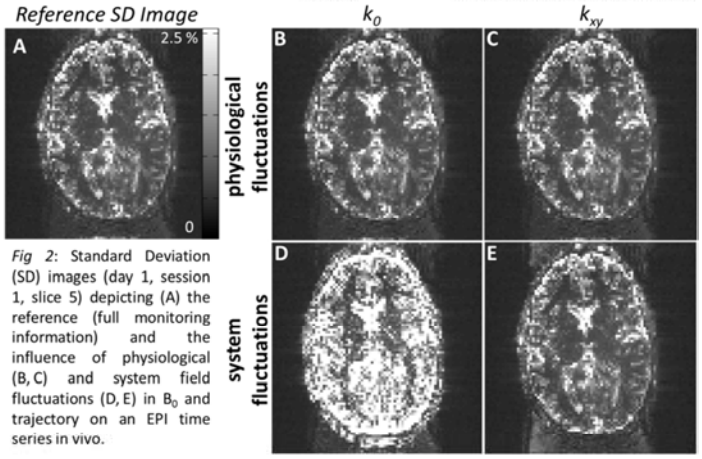

Fig 2: Standard Deviation (SD) images (day 1, session 1, slice 5) depicting (A) the reference (full monitoring information) and the influence of physiological (B, C) and system field fluctuations (D, E) in B_0 and trajectory on an EPI time series in vivo.

Results: The first PCs of k_0, k_x and k_y all exhibited a linear phase, corresponding to B_0 and gradient field offsets. (Fig. 1A,E,H). Additionally, k_x and k_y showed a modulation with the EPI readout frequency. In all PCA projections (Fig. 1B,F,I) a slow drift occurred for all time series, presumably due to system heating. Likewise, all projections were modulated with the breathing frequency (Fig. 1C,G,K, D), but no cardiac component was detected. With respect to fluctuations in the image time series, system-related field fluctuations induced a raised standard deviation (SD) level, for both k_0 (pixel shift) and k_{xy} (ghosting, Fig 2D,E), compared to the fluctuations in the reference reconstruction (2A). Physiological field fluctuations, on the other hand, hardly altered the SD images (Fig 2B,C). Consequently, in an ROI analysis, system fluctuations in k_0 induced the most severe SFNR losses, amounting to more than 42 % in grey matter (GM) and 25 % in white matter (WM). System fluctuations in k_{xy} induced a SFNR loss of 1 % in WM and 0.7 % in GM (Fig. 3). In contrast, physiological fluctuations in the encoding fields accounted for an SFNR loss of less than 0.5 % (k_0: 0.4 % in GM and 0.2 % in WM; k_{xy}: 0.1 % in GM and 0.02 % in WM, Fig. 3).

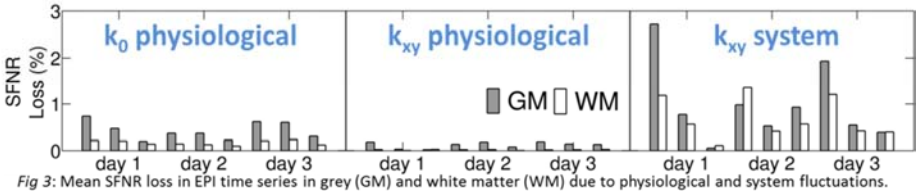

Fig 3: Mean SFNR loss in EPI time series in grey (GM) and white matter (WM) due to physiological and system fluctuations.

Discussion: Despite robust detection of physiologically induced field fluctuations using concurrent magnetic field monitoring, the observed SFNR losses were small at 3T. The results were reproducible in nine repeated measures of a single subject. The reported effect size of physiological fields may, however, be a conservative estimate, given subject geometry and BMI. In general, correcting for system-induced fluctuations in the encoding fields increased the SFNR considerably, especially when including fluctuations in the B_0 field.

References: [1] Barmet et al, 2010; Proc.ISMRM.10, p.216; [2] Pearson, K, 1901 Phil. Mag. S. 6, p.559-572, [3] Barmet et al, 2008; MRM.60; [4] Pruessmann et al, 2001; MRM.46;