Fast fMRI in nonhuman primates at 4.7T with multiband EPI and a 4 Tx/Rx + 1 Rx phased-array concept

Dávid Z. Balla, Hellmut Merkle, Franek Hennel[#], Thomas Steudel, Yusuke Murayama, Rolf Pohmann, Klaus Scheffler, Nikos K. Logothetis
Max Planck Institute for Biological Cybernetics, Tübingen, Germany; [#] Insitute for Biomedical Engineering, ETH Zürich, Switzerland

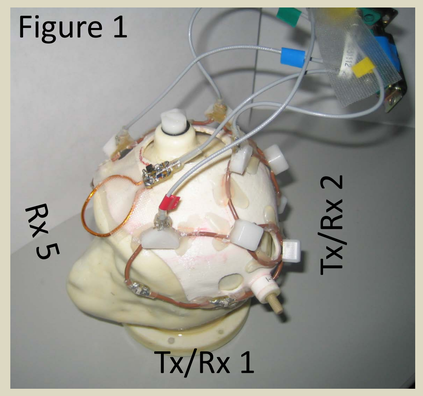
Purpose / Introduction

Physiology of neural systems in the brain is a field where fMRI unfolds its unique potentials (i.e. spatial coverage, noninvasiveness), but also clearly shows its limitations. The current technical possibilities combined with the inverse relations between signal-to-noise ratio and acquisition sampling rate, as well as between spatial resolution and full gradient encoding repetition rate, limit the acquisition speed and reduce the range of applications in basic neuroscience. In order to approach the timescale of dynamic processes in the brain of nonhuman primates and to detect the faint BOLD contrast induced by the transient activation of neural groups or global baseline changes, we developed RF-hardware, acquisition sequence and offline reconstruction pipeline for whole-brain fMRI subsampled in two dimensions.

Subjects and Methods

The 26cm inner diameter of the BGA26SL gradient system in our vertical bore Bruker BioSpec 47/40 MR scanner and the 3-point monkey-head stereotaxic system demanded a compact transmit-receive RF-coil-array solution (Figure 1). The water-proof coil components were mounted onto individual 3D-printed head-fixation helmets. Four loops were used for transmission in a circularly polarized manner and were decoupled by overlap. The quality of excitation homogeneity was not sufficient for solutions with more than 4 loops, since the size of the loops had to be reduced for decoupling and positioning. The same four loops were used for reception with a fifth smaller loop added to cover the frontal part of the brain. Power splitters, TR-switches, DC-control, bias-Tees and low noise preamplifiers were custom built and integrated in a stand-alone coil-interface.

Figure 1



Bruker's EPI acquisition method in Paravision 6.0.1 was modified to support calculation and parameter handling of multiband (MB) RF-pulses with programmable spacing, automatic sequence adaptation for blipped simultaneous multi-slice imaging with variable CAIPI-shifts [1], and manual control of some low-level EPI parameters directly from the method in advanced user mode. Figure 2 shows the pulse program for the minimum number of phase blips with MB parameters set as shown in the grey inset and slice orientation tilted around the x-axis (read-out direction, see image inset). Protocol parameters were optimized for SNR per unit time with a gradient duty cycle at limit, based on the primary criterion to achieve whole-brain coverage (18-22 slices of 2mm thickness) within 500ms. For this we took advantage of the original in-plane acceleration handling of the EPI method, which reduced distortions due to long echo-spacing, and combined it with the novel MB acceleration functionality. Fully sampled reference datasets with the same echo-spacing, and the number of segments set to the in-plane acceleration factor, were acquired independently. We tested 2D-GRAPPA [2], 2D-SENSE [3], slice-GRAPPA [1] and split-slice-GRAPPA [4] for the reconstruction of missing data. One step techniques (2D-GRAPPA and 2D-SENSE) suffered from significant leakage artifacts and the expected benefit was not gained by split-slice-GRAPPA, since this algorithm calculates the weights from the reference dataset only, whereas slice-GRAPPA can use source-points from the accelerated dataset. Hence, our pipeline used slice-GRAPPA preceded by 1D trajectory and phase correction.

Results

Figure 3a presents two slices from the reference dataset (2 segments, no MB, 20 slices), Fig. 3b the best case reconstruction of the two slices unfolded from a reduced version of the reference image (2 bands, 2x in-plane acceleration, FOV/2 CAIPI-shift), Fig. 3c the reconstruction from accelerated acquisition data (TR = 500ms, 0.9x0.9x2.0mm³), Fig. 3d the BOLD-activation map based on a visual stimulation paradigm ([16rest 8stim 36rest]x20 visual stimulation of the left eye with homogeneous light impulses flickering at 32Hz), Fig. 3e the temporal SNR-map and Fig.3f the average hemodynamic response from significantly activated voxels (t-test, p<0.01).

Figure 2

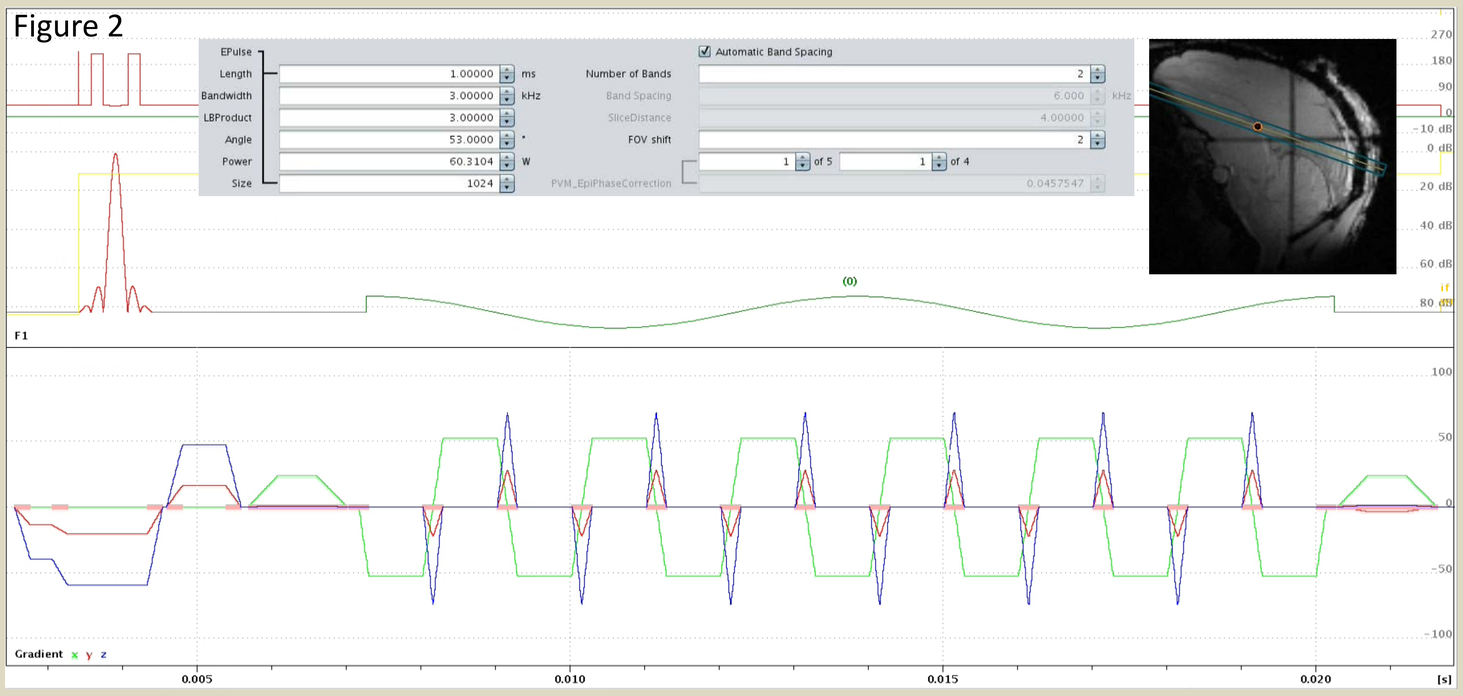
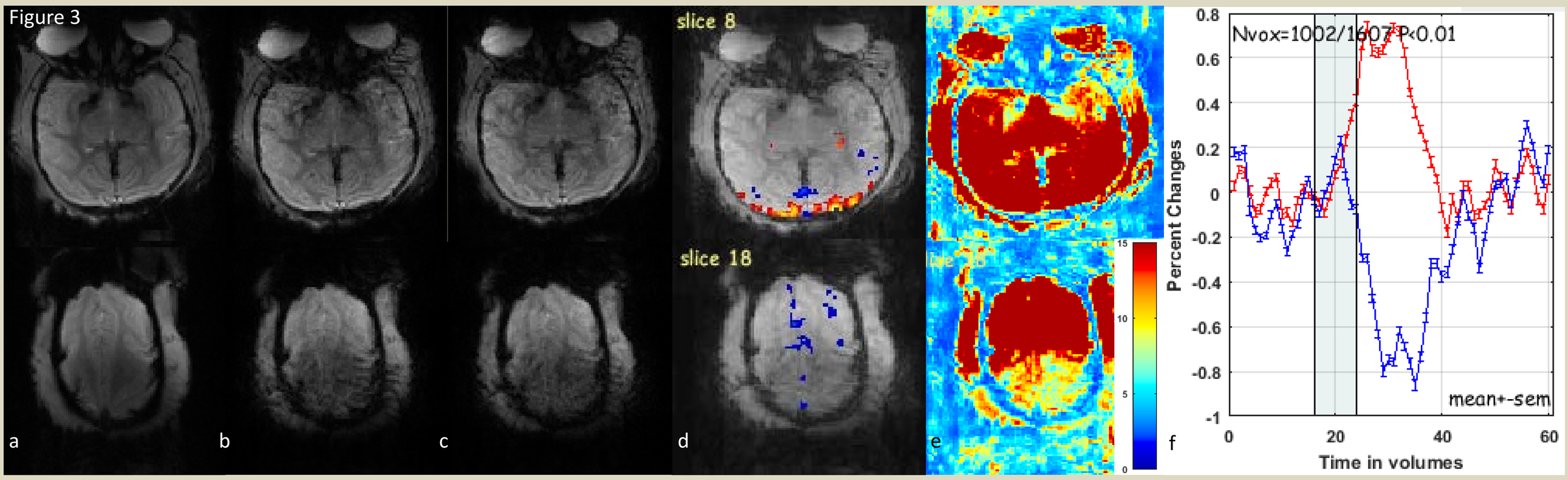


Figure 3



Discussion

Our setup and methods can produce high resolution whole-brain coverage datasets in 500ms and detect BOLD-contrast induced by standard stimulation paradigms. Sampling the hemodynamic response function at a high rate facilitates the detection of transient dynamic effects (i.e stimulus onset and offset bumps, as well as breathing "artifact" in Fig.3f).

References

[1] Setsompop K. et al., MRM 67:1210-1224 (2012)
[2] Zhu K. et al., Proc. Intl. Soc. Mag. Reson.Med. (2012) Abstract 518
[3] Zahneisen B. et al., MRM 74:1356-1362 (2015)
[4] Cauley S. F. et al., MRM 72:93-102 (2014)

Max-Planck-Institut
für biologische Kybernetik