Simultaneous fMRI Acquisition of Distributed Brain Regions with High Temporal Resolution

Jürgen Finsterbusch[1,2]

[1]*Department of Systems Neuroscience, University Medical Center Hamburg-Eppendorf, Hamburg, Germany,* [2]*Neuroimage Nord, Hamburg-Kiel-Lübeck, Germany*

Introduction

A single T2*-weighted echo-planar image [1] of the human brain can be acquired within 80 ms or less on a standard whole-body MR system. But in most fMRI experiments, distributed regions-of-interest (ROIs) are targeted, i.e. several slices must usually be covered. Thus, the experiment's temporal resolution is reduced accordingly and the different ROIs are not acquired at identical time points which both can hamper time-critical fMRI experiments. With a tailored 2D-selective RF excitation [2-4], several small target volumes can be excited at dedicated locations. Their MR signal can be acquired in a single projection image in which the ROIs can be discriminated unambiguously for an appropriate image orientation. Thus, the ROIs can be acquired simultaneously and with a high temporal resolution comparable to that of a single-slice acquisition. This is demonstrated in phantoms and, for ROIs in the visual and motor cortex, in healthy volunteers.

Methods

Figure 1a shows the basic pulse sequence used in the present study. Compared to standard FID echo-planar imaging, the initial slice-selective RF excitation is replaced by a 2D-selective RF (2DRF) excitation [2-4] based on a blipped-planar trajectory. The 2DRF excitation can excite arbitrarily shaped profiles within its trajectory plane, e.g. several distributed ROIs can be excited at dedicated locations with a single 2DRF pulse (see Fig. 1b). The signals of these ROIs are frequency and phase-encoded during the echo train. But because no encoding is performed in the slice direction, they are all projected into the image plane, independent of their coordinate in the slice direction, and can be acquired simultaneously with a single image acquisition (see Fig. 1c). Thereby, the minimum required field-of-view depends on the defined ROIs and can be smaller than the object without aliasing. For the performed experiments, rectangular ROIs were chosen with the long axis parallel to the image plane (defining the ROI size in the image plane) and the short axis perpendicular to the image plane (defining the effective slice thickness) as, e.g., ROI1 in Fig. 1b.

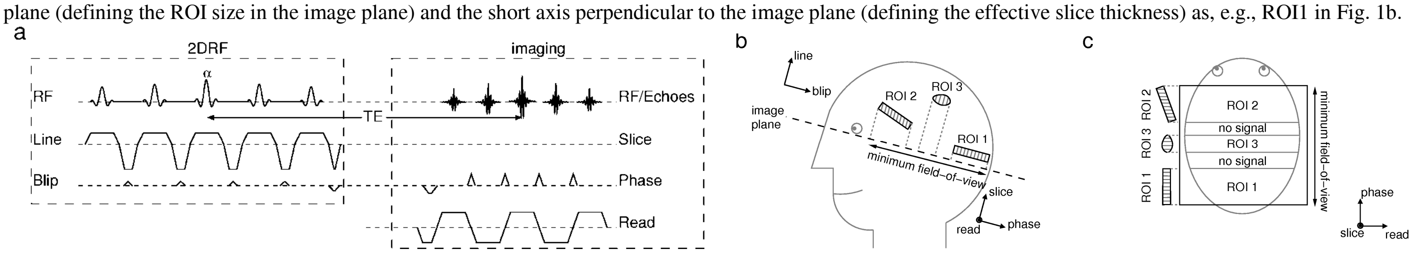


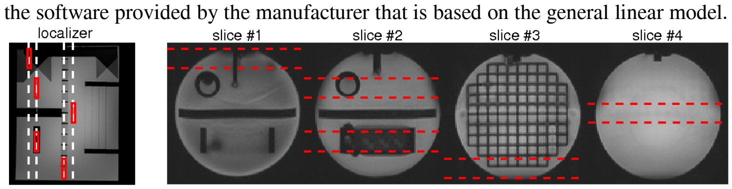
Fig. 1: (a) Basic FID echo-planar pulse sequence used in the present study with a 2D-selective RF excitation based on a blipped-planar trajectory. (b, c) Schematic example for acquiring three, distributed ROIs in a single image. With the 2DRF pulse, only these three ROIs are excited. Their signal projects into the image plane that is chosen to allow for an unambiguous discrimination of the ROIs in the acquired image. The gray lines in (b) sketch the shape and orientation of the voxels in the different ROIs. Note that for the shown setup the 2DRF excitation is supposed to be non-selective in the readout (left-right) direction.

The blip and line direction of the 2DRF excitation coincided with the phase-encoding and slice direction of the imaging plane (cf. Fig. 1a), respectively. The trajectory was set up with resolutions of 5 mm and 10 mm in the line and blip direction, respectively, and a field-of-excitation (distance of the side excitations appearing in the blip direction) of 208 mm yielding 21 trajectory lines and a 2DRF pulse duration of 16.9 ms. Up to five rectangular ROIs were defined as the desired excitation profile, all with a nominal slice thickness of 4 mm. The 2DRF envelope was obtained under the low-flip-angle approximation [4], i.e. taking the Fourier transformation of the desired excitation profile. It was filtered with a 2D Gauß function to minimize ringing artifacts. A single echo-planar image was acquired with a resolution of $2\times2\text{mm}^2$ (bandwidth per pixel 1502 Hz) and a parallel imaging (GRAPPA) [5] acceleration factor of 2 (echo time 30 ms, repetition time 80 ms, flip angle 15°).

Measurements were performed on a 3T whole-body MR system (TIM Trio, Siemens Healthcare) using a 32-channel receive-only head coil. Block-design fMRI experiments (10 s baseline, 10 s activation, 10 s control, nine blocks) were performed with a checkerboard stimulation vs. a grey screen. To demonstrate the temporal resolution achieved (80 ms), the display of the left half of the checkerboard was shifted by 240 ms (three images) compared to the right one. Healthy volunteers were investigated from which informed consent was obtained prior to the examination. A single-finger-to-thumb opposition task was performed during the visual control condition in some experiments for motor activation. fMRI data were analyzed with the software provided by the manufacturer that is based on the general linear model. Time courses of activated voxels were obtained with an in-house algorithm.

Results and Conclusion

In Fig. 2, the feasibility of the approach to acquire distributed ROIs simultaneously within a single-slice acquisition is demonstrated. Figure 3 shows the results of an experiment involving the finger tapping task with two ROIs in the motor and visual cortex being acquired in each image. In Fig. 4 it is shown that the delay between the visual activations in the left and right hemisphere caused by the time offset of the corresponding halves of the checkerboard, can be resolved with the high temporal resolution achieved in these experiments (80 ms). The presented approach allows for the simultaneous acquisition of distributed brain regions and could help to improve the temporal resolution of specific fMRI experiments.



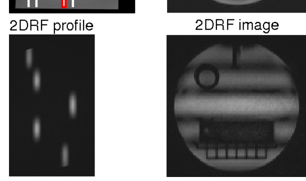


Fig. 2: Localizer and four slices (see white lines) of a phantom on which the red lines indicate the ROIs defined for the phantom experiments (upper). Excitation profile of the tailored 2DRF pulse and a corresponding single-slice image that covers all five ROIs simultaneously and unambiguously (lower).

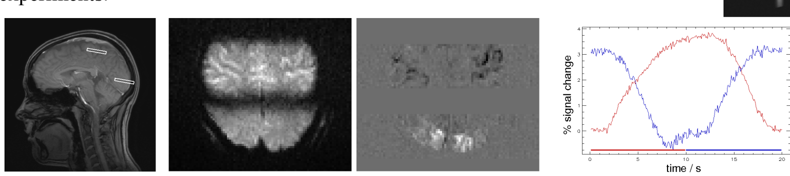


Fig. 3: Localizer, 2DRF image covering ROIs in the motor and visual cortex, corresponding t-map of a full experiment (nine blocks, single subject), and averaged signal time course of activated (|t|>3.5) motor (blue) and visual (red) voxels (from left to right).

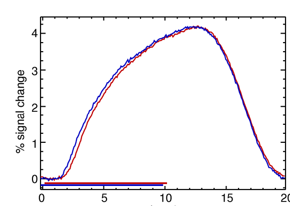


Fig. 4: Averaged time course (three volunteers, six experiments each with nine blocks) for activated voxels in the left (red) and right (blue) hemispheric visual cortex. The delay of the red curve agrees with the time offset between the two halves of the checkerboard.

[1] Mansfield P, J Phys C 10, 349 (1977) [2] Bottomley PA et al., J. Appl. Phys. **62**, 4284 (1987) [3] Hardy C et al., J Magn Reson 82, 647 (1989)
[4] Pauly J et al., J Magn Reson **81**, 43 (1989) [5] Griswold MA et al., Magn. Reson. Med. 47, 1202 (2002)