Gradient blips in the slice direction improve the flexibility of simultaneous fMRI acquisitions of distributed brain regions

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Introduction

Most fMRI experiments performed in the human brain rely on echo-planar imaging (EPI) [1] that is able to acquire a cross-sectional image within less than 80 ms on a standard whole-body MR system. However, to cover all regions-of-interest (ROIs) distributed in the brain multiple slices must be acquired and the temporal resolution of the experiment is reduced accordingly. Furthermore, the different ROIs are acquired at different time points which could hamper time-critical fMRI experiments. Recently, it has been shown that a tailored 2D-selective RF excitation [2-4] can be used to excite several, small target regions in the brain and acquire them in a single projection image [5]. With this approach, different target regions distributed in the brain can be acquired simultaneously and with the high temporal resolution of a single slice measurement [5]. However, in order to distinguish the signals of the different target regions unambiguously, they must not overlap in the projection image which constrains the position of the ROIs and the orientation of the projection plane. Here, the underlying pulse sequence is extended by gradient blips in the slice direction that are applied between the echoes in order to shift the projections of the different target regions relative to each other which is similar to blipped CAIPIRINHA [6] and related methods [7]. Thus, the positions of the ROIs and the image plane can be chosen more flexibly as is demonstrated in phantoms and in vivo in the human brain.

Methods

In the pulse sequence (Fig. 1a), the initial slice-selective RF excitation of a conventional FID-EPI sequence is replaced by a 2D-selective RF (2DRF) excitation [2-4] based on a blipped-planar trajectory that can excite arbitrarily shaped profiles within its trajectory plane, e.g. several distributed ROIs as shown in Fig. 1b. The signals of these ROIs are acquired in a single image with frequency and phase-encoding and can be distinguished unambiguously if the ROIs' projections into the image plane do not overlap. In order to improve this separation, gradient blips can be applied between the echoes in the slice direction (see Fig. 1a). These blips effectively tilt the projection plane by an angle that increases with the ROIs' distance from the isocenter in the slice direction (see Fig. 1b) and, thus, can shift the ROIs' projections relative to each other to distinguish their signals in the image (see Fig. 1b and c). As a consequence, the positions of the ROIs and the image plane can be chosen with more flexibility. Such or similar blips and image shifts have previously been used in simultaneous multi-slice acquisitions to improve the reconstruction [6,7].

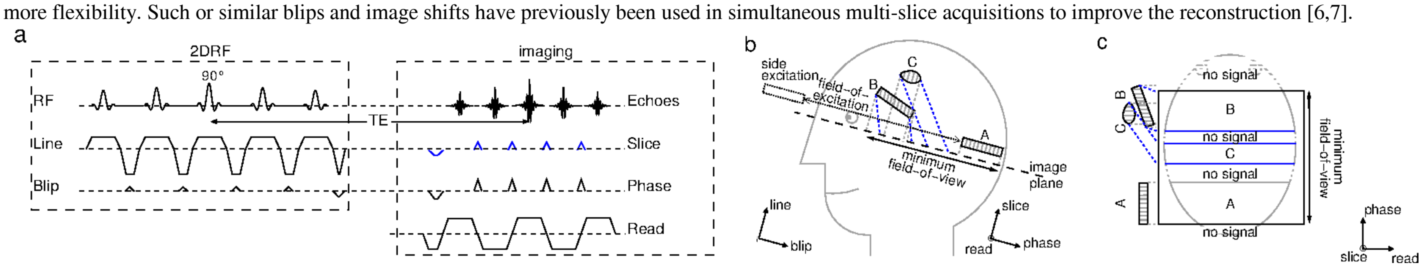

Fig. 1: (a) Basic FID echo-planar pulse sequence used with a 2D-selective RF excitation based on a blipped-planar trajectory. The imaging gradients in the slice direction (blue) introduce a phase shift from echo to echo that increases with the distance form the isocenter. (b, c) Schematic example for acquiring three ROIs with two of them (ROIs B and C) overlapping with a conventional projection (dashed gray). With the phase shifts introduced by the blip gradients in the slice direction, the projection direction (dashed blue) is tilted by an angle that increases with the distance from the isocenter and allows separating the two ROIs in the image.

Measurements were performed on a 3T whole-body MR system (TIM Trio, Siemens Healthcare) using 12-channel (phantom) and 32-channel (in vivo) head coils (both receive-only). 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 2DRF trajectory had 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 210 mm yielding 21 trajectory lines and a 2DRF pulse duration of 16.9 ms. Two or three rectangular ROIs with sizes in the blip direction between 28 and 48 mm (nominal slice thickness 4 mm) were used. The 2DRF envelope was obtained under the low-flip-angle approximation [4], i.e. taking the Fourier transformation of the desired excitation profile, and was filtered with a 2D Gauss function to minimize ringing artifacts. EPI was acquired with an in-plane resolution of $2\times2mm^2$ (bandwidth per pixel 1502 Hz) and a parallel imaging (GRAPPA) [8] acceleration factor of 2. Block-design fMRI experiments (16 s activation, 16 s control, six blocks, repetition time 80 ms, echo time 30 ms, flip angle 15°) were performed with a checkerboard (4 stimulation vs. a grey screen during which finger tapping (single-finger-to-thumb opposition) was performed. Data were analyzed with the software provided by the manufacturer based on the general linear model.

Results and Conclusion

Fig. 2 demonstrates the functionality of the extended approach in a water phantom and in vivo, respectively. Two ROIs chosen in different slices overlap in the conventionally acquired image but can be separated when applying the blip gradient pulses in the slice direction. An activation map of the fMRI experiments is presented in Fig. 4 showing activation in the separated visual and motor cortex ROIs.

The presented extension improves the flexibility for simultaneous acquisition of distributed brain regions which could help to improve the temporal resolution of specific fMRI experiments.

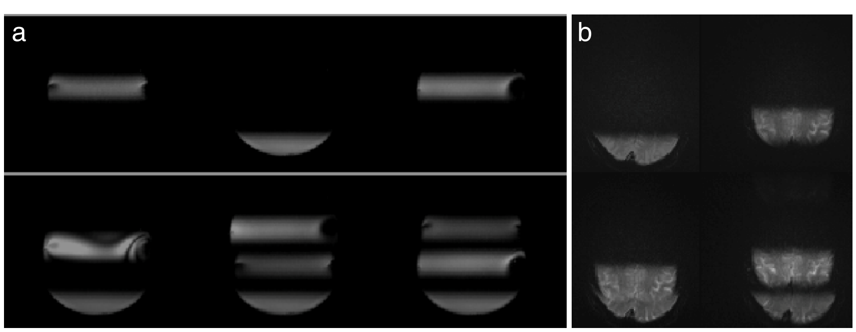

Fig. 2: Feasibility of the presented approach in (a) a phantom and (b) in vivo. The individual ROIs defined (upper) overlap in a conventional projection image (lower left) but are separated with the blip gradients (lower center / right; two different blip polarities are shown for the phantom).

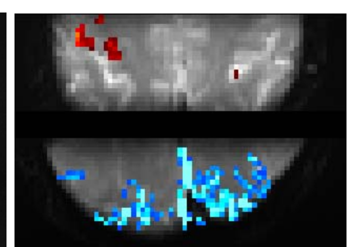

Fig. 3: Map of visual (blue) and motor (red) activatiopn for the separated ROIs shown in Fig. 2b.

References

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