Submillimeter fMRI at 3T using Long Axis PROPELLER-EPI

Martin Krämer[1], and Jürgen R Reichenbach[1]

[1]*Medical Physics Group, Department of Diagnostic and Interventional Radiology I, Jena University Hospital, Jena, Germany*

Introduction

Recently, it has been shown that the *periodically rotated overlapping parallel lines with enhanced reconstruction – echo planar imaging* (PROPELLER-EPI) technique [1] is not only suitable for performing *functional magnetic resonance imaging* (fMRI) [2,3], but also enables fast acquisition of high resolution T_2^*-weighted images at 3T [4]. Even with fast gradient echo readout, sub-millimeter in-plane resolution can be easily achieved. In our present work, we describe the capabilities of long axis PROPELLER-EPI for high resolution functional imaging at 3T.

Methods

Continuously rotated *long axis PROPELLER* (LAP) blades were acquired with fast gradient echo readout (Fig. 1). For image reconstruction a sliding-window reconstruction was used as described in [2], allowing for updating a new image to be reconstructed with each newly measured blade. In order to achieve high spatial resolution 2×GRAPPA acceleration was used in phase encoding direction, thus effectively reducing the amount of measured *k*-space lines and consequently echo time. To further reduce the echo train length, a high acquisition bandwidth of 180 kHz was used. Ten blades were combined to fill *k*-space completely with TE of 36 ms and 320×50 acquisition matrix size. With a FOV of 220 mm × 220 mm the achievable in-plane resolution was 0.7 mm × 0.7 mm. Ten slices, each with thickness and inter-slice distance of 2.5 mm, were measured with TR of 1000 ms. Geometric distortions were corrected using multi-frequency reconstruction [5] on the blade level, i.e., blades were corrected individually prior to their combination to full *k*-space. The multi-frequency reconstruction was based on high resolution field maps acquired for each blade by using a multi-echo reference scans [6] with the same size and orientation as the blades. The PROPELLER-EPI sequence was implemented on a clinical 3T whole-body system (TIM Trio, Siemens Medical Solutions) using *object oriented development interface for NMR* (ODIN) for sequence design [7] and a custom Matlab framework for MRI image reconstruction.

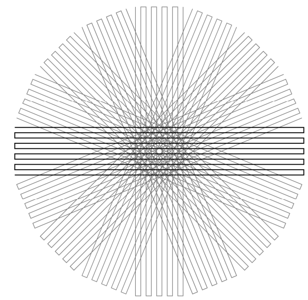

Fig. 1. LAP PROPELLER-EPI scheme.

Block design fMRI stimulation was achieved by right-handed sequential finger tapping of a healthy subject. Activation and resting periods of 20s and 30s were repeated 12 times, resulting in total scan duration of 10 minutes. Image analysis was performed using a standard fMRI analysis protocol of SPM8, i.e., motion correction, minor spatial smoothing with a 1 mm² kernel and FWE corrected threshold of $p < 0.05$. Activation clusters were mapped on the first repetition of the measured data.

Results

Figure 2 demonstrates that well localized activations in the motor cortex were obtained with very high spatial resolution. Spatial resolution of the PROPELLER-EPI data is sufficient to delineate anatomical structures with high quality, offering the possibility to avoid an additional anatomical reference scan. Even though some PROPELLER-EPI reconstruction artifacts are present due to the multi-frequency reconstruction in some outer brain areas, the functionally activated areas are free of any artifacts.

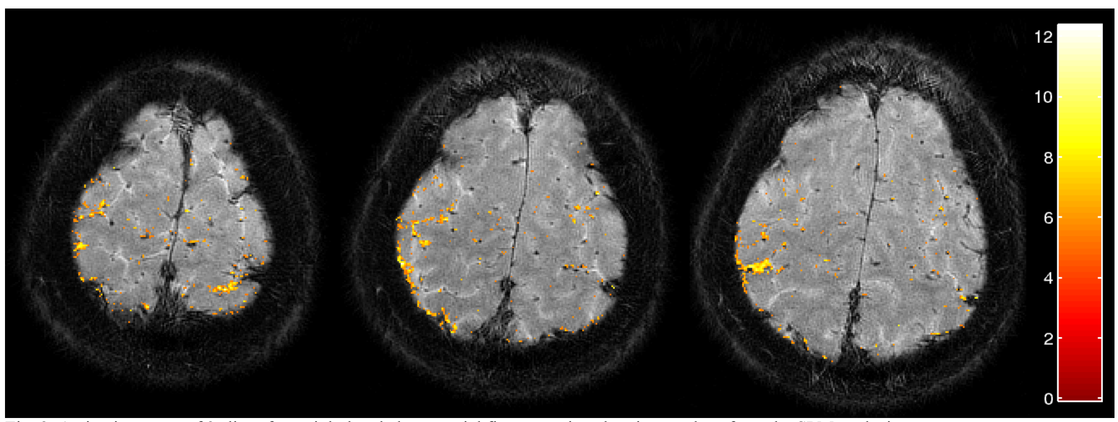

Fig. 2. Activation maps of 3 slices from right handed sequential finger tapping showing t-values from the SPM analysis.

Discussion

Using LAP PROPELLER-EPI enables high resolution fMRI at 3T with sub-millimeter in-plane resolution. Only moderate acceleration was used (2×GRAPPA) on a clinical 3 T scanner, demonstrating that no expensive hardware is required to perform high resolution fMRI within an acceptable scan time, i.e., in 10 min or less. The advantage of using LAP over the often used short axis (SAP) sequence [3] is a more efficient sampling of *k*-space data when very high acquisition matrices are used. With matrices as large as 320 data points, SAP requires partial Fourier acquisition of at least 5/8 or 6/8 to keep the readout train length within acceptable levels. Furthermore, the echo time would be very long with SAP if the readout is sampled from outer *k*-space areas towards the centre. Using a centre out acquisition scheme would start the readout too close to the *k*-space centre, reducing the echo time below 20 ms while creating strongly decreased signal for outer k-space areas due to significant T_2^*-decay during the long readout. With LAP the readout is much more balanced since no partial Fourier is required in phase encoding direction, resulting in echo times always at the centre of the readout train. Although with large matrices the readout time for single *k*-space lines is getting substantially longer than what seems feasible for EPI readout, use of large acquisition bandwidths of 180 kHz or even higher makes it possible to acquire data fast enough to keep the time between two readout lines sufficiently short and the resulting geometric distortions manageable. To obtain even higher spatial resolutions or to apply LAP PROPELLER-EPI at higher field strengths with shorter echo times more and thus narrower blades can be used in combination with partial Fourier acquisition in readout direction or with higher GRAPPA acceleration factors (e.g., factor 3).

References

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