Spin-Echo fMRI of the temporal lobe in awake, behaving monkeys at 7T

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Introduction

Susceptibility gradients from the ear canal result in distortion and signal loss in EPI images. This results in loss of functional activation in areas adjacent to the ear canal, like the temporal lobes. Although signal loss and distortion already occur at low field, at 7T the signal loss is so severe that no functional activation is seen in GE-fMRI of these areas. We are interested in fMRI of the entire visual ventral stream in awake monkeys; i.e. the areas from the occipital lobe to the inferior temporal cortex, because the ventral pathway is crucial for object recognition [1]. To overcome the susceptibility problem, we used SE-EPI, which allowed us to recover functional activation in areas affected by susceptibility gradients. In addition, SE-EPI has the advantages that the functional signal is more specific to gray matter [2], and it is less sensitive to B_0 variations due to motion.

Methods

Experiments were done in monkeys (*macaca mulatta*) weighing 9-15 kg, while the monkeys were viewing movies. The scanner (Bruker Biospec 7T/60v), experimental setup, behavioral paradigm and methods and hardware to control motion and behavior, have been described elsewhere [3,4]. A custom-designed volume coil was used. For GE-fMRI, 11 slices were acquired along the temporal lobe with slice thickness 2 mm, and a 2-segment EPI was used, with FOV of 12.8x9.6 cm, matrix 96x64, TE/TR 19/1000 ms. For SE-fMRI, 11-17 slices were acquired, using a 2-segment SE-EPI, with FOV of 9.6 to 12.8 cm, and matrix 64x48 or 64x64, TE/TR 40/1000 ms. The SE-EPI was optimized to reduce susceptibility artifacts, and based on behavioral constraints. Reference images were a high resolution FLASH, high-resolution SE-EPI, and high-resolution 3D-MDEFT. The MDEFT was acquired under general anesthesia at 4.7T [5]. 3D-FLASH images were used for fieldmap correction [6]. A trial-based paradigm was used, with trial duration of about 20 s and stimulus presentation 8 s. The monkeys were trained to sit still and fixate during the trial, and were given a juice reward after each successful trial. Data analysis consisted of selection of successful trials, motion correction, normalization and statistical analysis, clustering, brain extraction, fieldmap correction, and registration to a high-resolution anatomical image (MatLab, SPM2, FSL).

Results

Figure 1A shows a FLASH reference image through the inferior temporal lobe; Fig. 1B shows the functional map obtained using GE-EPI on the raw EPI image for the same slice. Although strong functional activation is present in early visual areas, no functional signal is seen in the inferior temporal cortex (IT) due to signal dropout in the raw EPI. Signal dropout in the EPI is due to the proximity to the ear canal. Based on electrophysiological evidence in the macaque [7,8], functional activation is expected along the inferior temporal cortex.

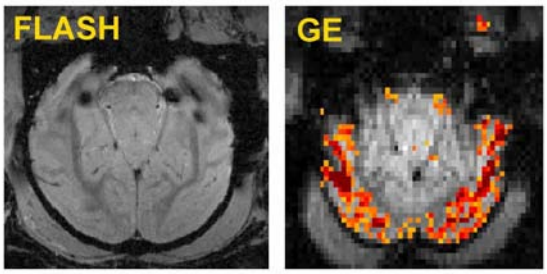

Figure 1 (monkey B04): anatomy and GE-BOLD map

Figure 2 shows the functional map obtained using SE-EPI overlaid on a high-resolution 3D-MDEFT. The figure shows functional activation along the entire temporal lobe, including in areas right next to the ear canal. The SE-EPI did not have signal dropout, and the activation patterns match the known visual areas in the macaque based on electrophysiology [7,8]. Field map correction was necessary to correct for geometrical distortions in the SE-EPI; the strong susceptibility gradients from the ear canal caused shortening of the anterior temporal lobes in the EPI. Figure 2 shows that the fieldmap correction and image registration procedure result in accurate registration of the activation map to the anatomical reference.

Functional activation coincided with gray matter, as is expected from the higher specificity of the SE-EPI to gray matter [2].

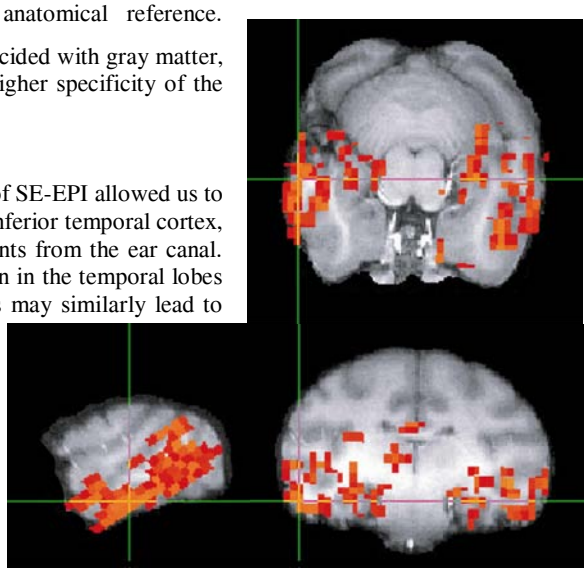

Fig. 2 (monkey L04): SE-BOLD functional map on MDEFT

Conclusion

The results show the feasibility of whole-head fMRI in awake monkeys at 7T. The use of SE-EPI allowed us to obtain functional activation in the entire ventral visual pathway, including areas in the inferior temporal cortex, where typically no functional activation is seen due to the strong susceptibility gradients from the ear canal. The extensive activation in the temporal lobe suggest that a lack of functional activation in the temporal lobes when GE-BOLD is used, is due to technical limitations, and using SE-EPI in humans may similarly lead to improvements in functional activation in inferotemporal areas.

Author contributions: J.G. and S.P.K. contributed equally

Acknowledgements: We thank Thomas Steudel for technical support, and Steffen Stoewer and Chris Petkov for use of their monkey. Supported by the Max-Planck Society

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