FMRI of the Medial Temporal Lobe Using Balanced Steady State Free Precession

M. H. Chappell[1], H. Lehn[1], P. E. Goa[2], A. Kristoffersen[2], R. L. Tijssen[3], A. Håberg[1], and K. L. Miller[3]

[1]ISB, NTNU, Trondheim, Sør Trondelag, Norway, [2]Department of Medical Imaging, St Olavs University Hospital, Trondheim, Sør Trondelag, Norway, [3]Centre for Functional MRI of the Brain (FMRIB), University of Oxford, Oxford, United Kingdom

Introduction

Conventional BOLD fMRI can suffer from distortions, blurring, and signal dropout in regions with large susceptibility gradients such as the medial temporal lobe (MTL). This compromised image quality is problematic for activation studies of the MTL with BOLD, and indirectly limits the achievable spatial resolution. FMRI with balanced steady state free precession (bSSFP) has been shown to be effective without suffering from these characteristics [1,2]. Furthermore, bSSFP is well-suited to 3D imaging, making isotropic high-resolution functional acquisitions possible. Acquisitions can be either in the transition band (tbSSFP) or the passband (pbSSFP). One drawback with bSSFP is its sensitivity to any underlying spatial or temporal B_0 drift, with tbSSFP being more prone to image degradation than pbSSFP. B_0 instability or inhomogeneity can result in banding artifacts. This study demonstrates the use of pbSSFP to achieve high resolution functional images from neuronal activation, including in the MTL. Previous studies using bSSFP in the visual cortex have achieved a resolution of $1\times1\times2$ mm^3 using tbSSFP [1] and of $2\times2\times2$ mm^3 using pbSSFP [2]. Also, a hypercapnia study achieved $2\times2\times5$ mm^3 with pbSSFP over the whole brain. In this study we used a stimulus-rich paradigm known to reliably activate hippocampal/parahippocampal regions, as well as the visual area [3]. We achieved a resolution of $1.5\times1.5\times1.5$ mm^3 in these areas using pbSSFP with single subjects.

Methods

A 3T Siemens Trio was used with the manufacturers' 32-channel head coil, using a 3D stack-of-segmented EPI trajectory covering a $128\times128\times20$ matrix with bandwidth 1776 Hz/pixel. The restricted FOV of $196\times196\times30$ mm^3 was aligned with the major hippocampal axis, with shimming targeted from the hippocampal region out to the neocortex. This was done to minimize the B_0 inhomogeneity, and therefore the banding artifact, in the volume of interest. A large time-bandwidth product (TBW=16) was used to minimize aliasing in the slice (z phase encode) direction. Because of the large susceptibility gradients in the MTL and pbSSFP being less sensitive to these, we chose to use pbSSFP rather than tbSSFP for this study. A flip angle of 30° placed the acquisition in the passband. TR (22 ms) was chosen heuristically as a compromise between maximizing functional contrast (with a high TR) while reducing the banding artifact (requiring a low TR). There were 21 echoes recorded after each excitation. The time resolution was 2.7 s/vol. The stimulus was a memory-encoding paradigm with alternating blocks (20 s each) of novel and repeated stimuli, lasting a total of 420s. The presence of bands in the SSFP images (away from the passband region) creates high-contrast boundaries that can partially correlate with the stimulus paradigm, leading to artifactual "activations"[2]. Since any activation in these regions is known a priori to be unstable, and quite likely artifactual, we defined an inclusion mask (Fig.1b), outside of which activation was rejected. This mask was calculated by first high-pass filtering the mean SSFP image, then applying an edge filter and clustering the resulting edge image to find contiguous regions of high-contrast boundaries, which were excluded from the mask. After applying this mask to the statistical images, we used TFCE [4] to identify activation clusters.

Fig.1. Processing pipeline: a. raw data; b. inclusion mask; c. "raw" z-statistics ($z > 2.3$); d. final masked and clustered results.

Results and Discussion

Using a small shim volume to ensure we did not have banding in the volume of interest made the images prone to more banding 'outside' the shim volume. This was addressed by using the inclusion mask. For comparison Fig.1 shows images at different stages of the processing of one subject. The activations from the processed data in the hippocampal/parahippocampal (Fig.2a) and visual area (Fig.2b) are consistent with the applied stimuli. These results demonstrate the ability of pbSSFP to acquire high resolution functional images in these regions for a single subject. This corroborates other recent works showing the ability of bSSFP to acquire high resolution functional images in the visual cortex. The novelty of the results presented here is the resolution obtained in the MTL. These bSSFP images are essentially without the distortion and signal dropout often associated with conventional BOLD imaging in this region. However, the presence of SSFP bands must be addressed, and one possibility is to mask out banding regions, as described here.
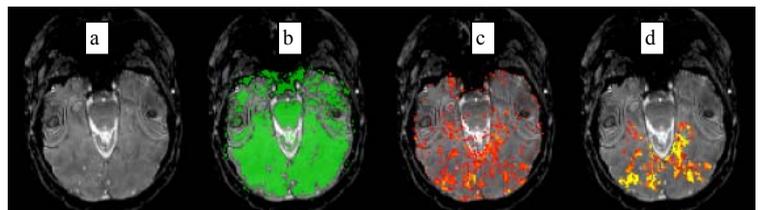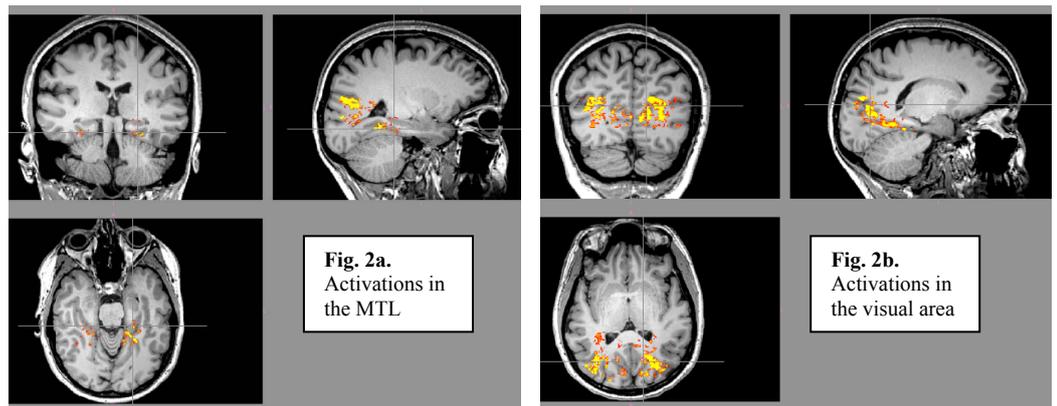

Fig. 2a. Activations in the MTL

Fig. 2b. Activations in the visual area

References

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