Determination of acoustic noise characteristics and development of silent EPI for auditory fMRI

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Introduction:

MR scanner noise is often a problem in fMRI studies, especially in auditory experiments. The BOLD signal induced by the scanner noise may interfere with the auditory fMRI signal [1]. Additionally the scanner's sound pressure level (SPL) of up to 110 dBA causes discomfort or anxiety in many patients [2].

In this work, a silent EPI sequence using a pure sinusoidal readout gradient is presented with a noise reduction of about 11 dBA compared to a conventional EPI sequence with the same imaging parameters. The new sequence was tested in an fMRI experiment with auditory stimulation. In this block-design experiment, a reliable BOLD response of up to 6% signal change was detected in the primary auditory cortex.

Methods:

All measurements were performed at a 1.5 T scanner (Siemens Avanto; Siemens Medical Solutions, Germany). For the acoustic measurements, a capacitor microphone was used, which was connected to a PC outside the HF-cabin by a shielded cable. The measure setup was calibrated by a gauged sound pressure meter in a sound-proof room.

First, the scanner's acoustic response spectrum was determined. Therefore each gradient coil was switched purely sinusoidally with constant maximal amplitude of 10 mT/m while the frequency was varied in steps of 10 Hz from 300 Hz to 1500 Hz. The SPL of the individual steps was calculated by peak detection of the Fourier transform of the recorded noise.

On this basis a silent EPI sequence was developed, which switches the readout gradient sinusoidally with a frequency outside the acoustic resonance frequencies of the scanner. Both the SPL and the acoustic spectrum of the silent sequence were measured and compared to a non-noise-optimized EPI sequence with the same sequence parameters: bandwidth = 953 Hz/Px, TE = 55 ms, TR per slice = 115 ms, MAT=64x64, FOV = 256x256 mm^2, THK= 5 mm, α= 90°.

The new sequence was tested in an auditory MRI experiment with 3 volunteers. 25 consecutive axial slices per volume (TR = 2.9s) were acquired to cover the whole cerebrum. The simple block-design paradigm consisted of 90 images per slice, alternating 10 images at rest and 10 images during stimulation, which led to a total measurement time of 4:19 min. During the stimulation phase, a coherent text was read out to the volunteers [3]. Data post-processing was performed with the help of scripts based on AFNI [4], including motion correction and spatial smoothing (Hanning-Window, FWHM=6mm). A cross-correlation analysis was carried out with the theoretical time course (boxcar function convolved with the hemodynamic response function). Both the correlation coefficients and the percentage BOLD signal increase were calculated. The correlation coefficients were then transformed to a Z-score statistical map and overlaid to anatomical T1w images.

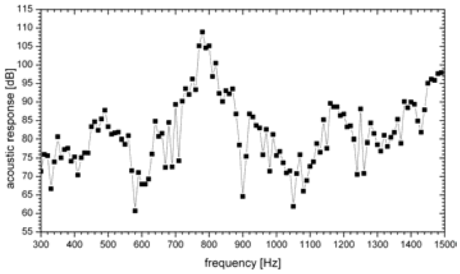

Fig. 1: measured acoustic response of the x gradient on sinusoidal switching (G_{max} = 10mT/m)

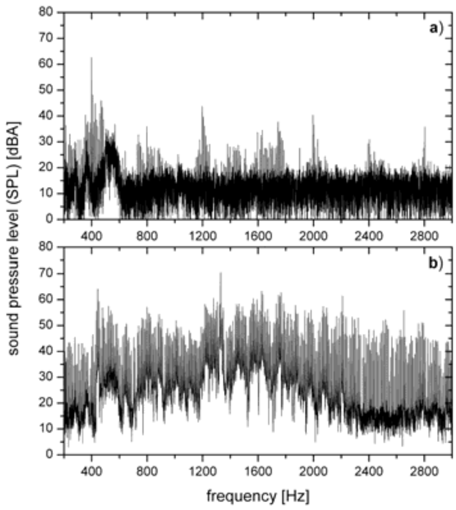

Fig. 2: frequency spectrum of a) the optimized silent sequence, b) conventional EPI sequence

Results:

Exemplary, the acoustic response spectrum of the x gradient is plotted in an interval from 300 Hz to 1500 Hz (Fig. 1). For a constant maximal gradient amplitude (10 mT/m) the acoustic response fluctuates up to 40 dB. Therefore, we optimized the frequency of the readout gradient to be 400 Hz, which is far beyond the scanner's acoustic resonances. In Fig. 2a, the acoustic spectrum of our optimized silent sequence is shown. By the use of sinusoidal readout gradients the acoustic spectrum is limited to a short interval. For comparison, the acoustic spectrum of a conventional EPI sequence with the same parameters is shown in Fig. 2b. The average noise of our silent sequence amounts to 66 dBA. It is reduction of 11 dBA, thus more than halving the loudness. Additionally, the acoustic spectrum of the optimized sequence is limited to a short interval whereas the standard sequence shows a broad noise frequency band.

In the auditory experiment significant activation in the primary auditory cortex was detected in all the three subjects with a peak signal change of up to 6% (Fig. 3). Additionally, in all the volunteers activation was found in the left middle frontal gyrus (Talairach -45,10,40) (Fig. 4), an area which is known to be involved in the consonant judgement [5].

Discussion:

An EPI sequence has been developed with more than 50% noise reduction compared to a conventional EPI sequence. Its acoustic spectrum is limited to a small interval around a dominant frequency component, the readout frequency.

In spite of a rather simple paradigm this sequence showed significant activation in an auditory fMRI experiment not only in the primary auditory cortex but also in other brain regions.

In future experiments the dependency of the acoustic BOLD signal on the sound pressure level and readout frequency will be studied. In addition the sequence will be optimized for 3T-systems, where the noise reduction is even more essential, because noise increases with rising B0-fields.

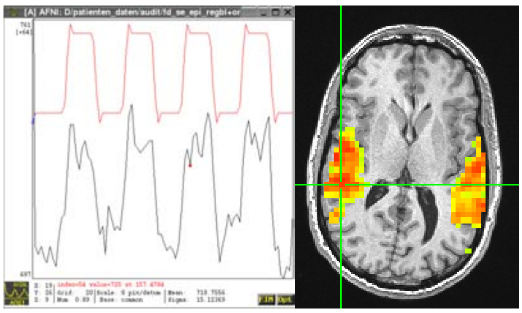

Fig. 3: signal time course (black) of one significant voxel (marked with the green cross in the right image) of the primary auditory cortex. In red: ideal time course.

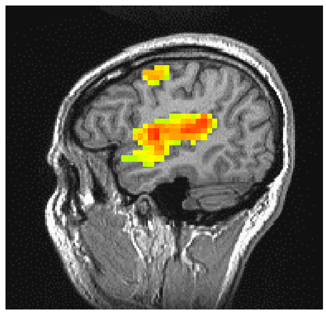

Fig. 4: Z-score statistical map (Z>2.6, p<0.005 corrected). Significant activation can be observed in primary auditory cortex and in left middle frontal gyrus.

References:

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