Benefit of parallel imaging techniques for silent EPI

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Introduction:

Huge acoustic noise is generated during MR image acquisition, particularly in fast sequences. In functional MRI (fMRI), where fast EPI techniques are commonly used, a sound pressure level (SPL) of up to 130 dBA can be measured on a 3T system [1]. In auditory fMRI experiments the noise can affect the BOLD signal and alter the results. In a previous work [2] we have shown, that a silent EPI sequence with a sinusoidal readout (RO) gradient reduces the noise by adjusting the gradient switching frequency (f_{RO}) to the scanner's acoustic frequency response function (AFRF). Optimal regions for f_{RO} are local minima of the AFRF, which are mainly located at lower frequencies (<700 Hz). However, a lower frequency limit is given by the echo time (TE), which is determined by the desired image contrast.

In this work our silent sinusoidal EPI sequence was combined with parallel acquisition techniques (PAT) to reduce the scanner noise by decreasing f_{RO}. This is possible because less k-space lines have to be acquired at constant resolution.

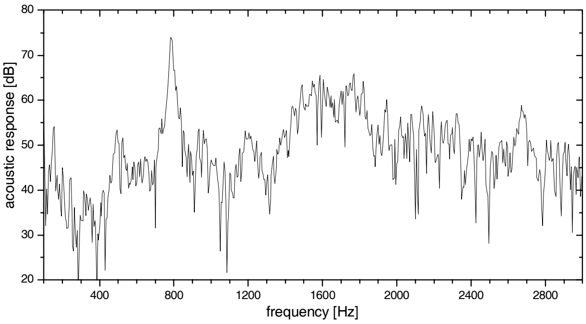

Fig. 1: *acoustic frequency response function (AFRF) of the x gradient coil*

No	Sequence	Parameter
i	manufacturer EPI-sequence	BW = 976Hz/Px, FOV = 220x220mm^2, Matr. = 64x64 Px, TE = 58ms, TR = 107ms (per slice),
ii	silent EPI, no PAT, pulsed PE grad.	BW = 976Hz/Px, f_{RO} = 407Hz, FOV = 220x220mm^2, Matr. = 64x64 Px, TE = 58ms, TR = 107ms (per slice),
iii	silent EPI, no PAT, const. PE grad.	BW = 976Hz/Px, fRO = 407Hz, FOV = 220x220mm^2, Matr. = 64x64 Px, TE = 58ms, TR = 107ms (per slice),
iv	silent EPI, PAT = 2, pulsed PE grad.	BW = 606Hz/Px, fRO = 253Hz, FOV = 220x220mm^2, Matr. = 64x64 Px, TE = 58ms, TR = 107ms (per slice),
v	silent EPI, PAT = 2, const. PE grad.	BW = 606Hz/Px, fRO = 253Hz, FOV = 220x220mm^2, Matr. = 64x64 Px, TE = 58ms, TR = 107ms (per slice),

Tab. 1: *parameter settings for the used sequences(i)-(v)*

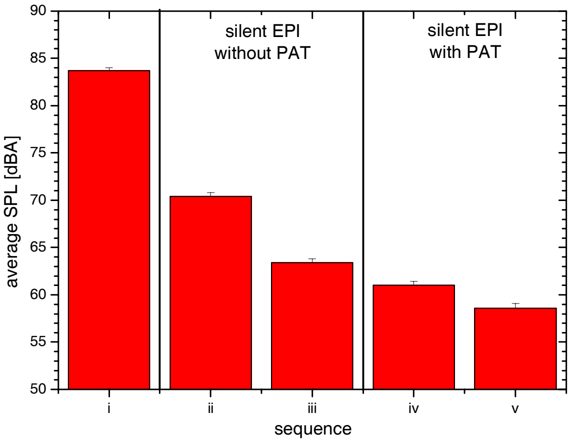

Fig. 2: *average SPL for the manufacturer sequence (i) and the silent EPI with parameter settings (ii)-(v)*

Methods:

The scanner noise L_p is mainly generated by Lorentz forces, which act on the gradient coils. By summing the convolution of the scanner's acoustic response function (ARF) with the gradient switching $G_i(t)$, this noise can be linearly approximated [3]. In frequency domain the convolution becomes a product of the acoustic frequency response function (AFRF) and the Fourier transform of the gradient switching:

$$L_p(t) \propto \sum_{i=x,y,z} ARF_i(t) * G_i(t) \qquad L_p(f) \propto \sum_{i=x,y,z} AFRF_i(t) \cdot FT(G_i(t))$$

Our measurements were performed on a clinical 1.5T whole body scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany). The AFRF of this scanner is measured for all gradient coils.

As we have already demonstrated [2] an EPI sequence using sinusoidal readout gradients is well suited to reduce the scanner noise. The Fourier transform of a sinusoidal gradient corresponds to a delta function with characteristic frequency f_{RO}, which is proportional to the ADC bandwidth. If f_{RO} coincides with a local minimum of the AFRF, the average SPL is reduced compared to common EPI sequences.

Keeping the frequency, and therefore also the bandwidth, as low as possible is generally of benefit, because first the human sense of hearing is less sensitive to lower frequencies and second, the readout gradient amplitude is reduced. However, a lower limit for f_{RO} is set by TE. As fewer k-space lines have to be acquired, the use of PAT allows the use of frequencies below this limit.

We compare the SPL of a conventional manufacturer EPI sequence to the SPL of four different parameter settings of the silent EPI sequence (tab. 1), two with and without PAT, respectively. As all four settings use sinusoidal RO gradients, regridding of unequally sampled data in RO direction is necessary. Sequences (iii) and (v) use a constant phase encoding gradient (PE) while the image is being acquired, instead of a pulsed PE gradient to switch to the following line. In these cases the k-space sampling density has to be corrected in PE direction as well.

The SPL was measured with a capacitor microphone, which was placed inside the magnet. It was connected to a PC outside the cabin via a shielded cable. The noise measurements were performed without the application of excitation pulses to reduce interfering signals on the acoustic signal.

Results:

An example for the scanner's AFRF is shown in fig. 1. In fig. 2 the average SPL is displayed for the five settings. With (83.7 ± 0.3) dBA the manufacturer EPI sequence causes the highest SPL. A reduction of the average SPL for decreased frequencies f_{RO} is visible. Further the use of PAT reduces the SPL by 7 dBA on average. The measured values for the silent EPI in units of dBA amount to (ii): 70.4 ± 0.3, (iii):63.4 ± 0.3, (iv):61.0 ± 0.3, (v): 58.6 ± 0.3.

The relative SNR is calculated for setting (iv) compared to setting (ii) and yields a factor of 0.94 with an error of 5%.

Discussion:

Fig. 2 demonstrates that the use of PAT reduces the average sound pressure down to 61.0 dBA and 58.6 dBA. In this SPL range the scanner's cryo pump becomes clearly audible. This noise level is comparable to the SPL of a calm conversation.

As the total image acquisition time remains constant in settings (ii) to (v), the SNR is not significantly reduced for the PAT sequences.

With this silent technique we will examine the benefit of the reduced scanner noise in auditory fMRI experiments.

References:

[1] Foster JR et al. [2000] J Magn Reson Imaging 12:157-163.
[2] Schmitter S. et al. [2006] Proc. ISMRM, 2814.
[3] Hadeen RA et al. [1997] Magn Reson Med 37:7-10.