ACOUSTIC NOISE OPTIMIZED DIFFUSION-WEIGHTED IMAGING (DWI)

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Target audience: This work aims for people who are interested in MR acoustic-noise experiments and patient comfort.

Purpose: There are several methods for acoustic-noise reduction in MR sequences such as hardware modification [1] as well as gradient design [2]. Up to now, acoustic-noise reductions have been investigated mostly for TSE and GRE clinical MR sequences [3, 4]. For example the use of parallel imaging and redesigned gradient waveforms can reduce acoustic-noise in EPI-BOLD imaging [5]. However, the acoustic-noise of diffusion-weighted imaging sequences can easily achieve over 100 dB(A) due to fast switching gradients as well as high gradient amplitude. In this work we present a modified prototype sequence based on diffusion-weighted, readout-segmented echo-planar imaging (rs-EPI) [7], which results in a significant reduction in acoustic-noise while retaining the image quality of a standard diffusion-weighted single-shot EPI sequence. This is achieved with an acceptable increase in imaging time and without the requirement for hardware modifications.

Methods: Figure 1 shows the pulse diagram for the rs-EPI sequence. After a diffusion preparation, two spin echoes are generated for collecting image and navigator data respectively. Multiple readout segments are acquired with different k_x offsets to achieve full k-space coverage; typical scanning protocols use between three and nine readout segments. The sequence is typically combined with parallel imaging using GRAPPA [8] and an acceleration factor of two, so that data sampling is only performed for every second k_y line. To reduce acoustic-noise level we developed and tested two major modifications:

a) the echo spacing (ESP) in the EPI readout was increased from 0.38ms to 1.0ms, leading to lower slew rates and less acoustic-noise. Thus the sampling bandwidth in read direction was decreased by the longer echo-spacing and in addition offers time for smooth blips between subsequent k_y lines.

b) The longer echo times due to the lower slew rates were compensated by applying an additional partial Fourier factor of 6/8 in k_y direction. This has the same approach as applying asymmetric echo in cartesian k-space sampling.

The acquired data with long ESP had a lower sampling bandwidth (1.0ms => 217 Hz/px) in read direction than the acquired data with high ESP (0.38ms => 868 Hz/px) and can be used for compensating SNR loss due to partial Fourier. Experiments were performed on a 3T MAGNETOM Skyra system (Siemens Healthcare, Erlangen, Germany), equipped with a 20-channel head/neck coil. Different imaging parameters were tested and acoustic-noise was analyzed using a Brüel&Kjaer Mediator 2238 Noise Meter by placing a microphone in front of the bore during a phantom measurement. Images were acquired from healthy subjects using: one scan at b=0 and three scans with b=1000s/mm² in three orthogonal directions. A GRAPPA acceleration factor of 2 was applied for all measurements. The partial Fourier reconstruction was performed using a Margosian algorithm after 2D navigator phase correction and combination of data from the different readout segments.

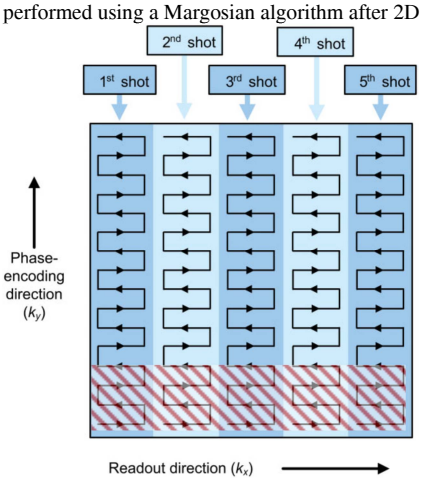

Figure 1: Illustration of k-space sampling scheme in the modified rs-EPI sequence. The shaded area is not acquired due to partial Fourier.[7]

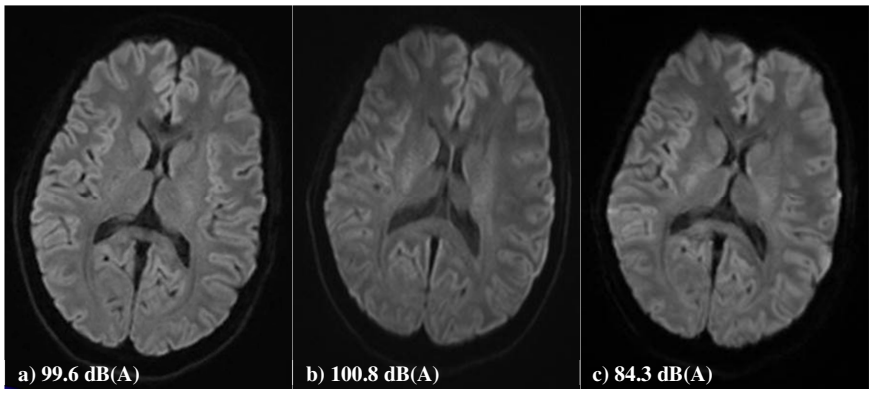

Figure 2: Comparison of trace-weighted images: a) standard rs-EPI with ESP 0.38ms, b) single shot EPI and c) quiet rs-EPI with ESP 1.00 ms and partial Fourier factor of 6/8 in the phase-encode direction.

Parameters	Average Noise load dB(A)	Imaging time
a) ESP: 0.38 ms, no PF , TR=5500ms,TE=70ms, 7 readout segments	99.6	3:03 min
b) ESP: 1.04 ms, PF 6/8, TR=5500ms,TE=98ms, single-shot	100.8	1:24 min
c) ESP: 1.00 ms, PF 6/8 , TR=5700ms,TE=85ms, 7 readout segments	84.3	3:44 min

Table.1: Imaging parameters and corresponding acoustic-noise values. Imaging parameters for all acquisitions: FOV: 240x240mm², matrix size 192x192, slice-thickness: 4mm, 25 slices, b-values of 0 and 1000s/mm² in three orthogonal directions were used.

Results: The results of the acoustic-noise measurements are shown in Table.1. A significant acoustic-noise reduction of 15.3 dB(A) was achieved compared to standard rs-EPI and 16.5 dB(A) compared to single-shot EPI. In figure 2 we show single image from each of the three protocols for comparison. Visual evaluation of the reference image (fig. 2a) and the image from the modified, quiet rs-EPI sequence (fig. 2b) shows differences between the two echo spacings of 0.38 ms and 1.00 ms. In the quiet image, T2 contrast decreases as well as image blurring; the main image information is retained. The TE could be kept short by applying partial Fourier, though ESP was increased. Overall, the image quality appears better than the standard single-shot EPI (fig. 2c). This is due to methodical different image reconstruction like zero-filling in single-shot EPI.

Discussion: The modified rs-EPI sequence with a partial Fourier acquisition in the phase-encoding direction allows DWI to be performed with reduced acoustic-noise. Image quality was even improved compared to standard single-shot EPI. To keep the high resolution of the standard rs-EPI sequence, a tradeoff between acoustic-noise and image quality could be made. Therefore the ESP could be increased to an intermediate value, such as 0.6 ms, for which a significant acoustic-noise reduction would still be achieved.

Conclusion: A clinical DWI sequence was addressed for acoustic-noise optimization. It is shown that the image quality can be maintained compared to standard single-shot EPI, whilst patient comfort is substantially improved.

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References: [1]. Katsunuma et al MRM 13, 129-144 (2001) [2]. Hennel F. et al. MRM Jul 42(1):6-10 (1999) [3] Hedeen, Edelstein, MRM 37:7-10 (1997) [4] Hennel, JMRI 13:960 –966 (2001) [5] Zwart et al. , NeuroImage 16, 1151–1155 (2002) [7] Porter and Heidemann MRM 62:468–475 (2009) [8] Griswold et al. MRM 47;1202-1210 (2002)