Reduction of Acoustic Noise to Improve Patient Comfort Through Optimized Sequence Design

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TARGET AUDIENCE: This work is relevant to an audience interested in improving patient comfort or performing MR experiments that require low acoustic noise.

PURPOSE:. Some currently available solutions to reduce acoustic noise in MR sequences involve enclosing the gradient coils into a vacuum chamber, or rotate or change gradient fields mechanically[1], or use limited bandwidth pulse sequences[2] . This is, however, at the cost of manufacturing expense, complexity and gradient performance. Recently, the use of parallel imaging and redesign of gradient waveforms have demonstrated reduction of acoustic noise in Echo Planar Imaging (EPI)[3] . The purpose of this work is to extend such principles to other standard clinical MR sequences, in order to achieve reduced acoustic noise without cost of image quality nor imaging time, and without any hardware modification.

THEORY: In this work, every gradient waveform in a pulse sequence was optimized for acoustic performance by using slower gradient slew rate while attempting to keep the same total acquisition time and inter-echo spacing. Using such an approach, many bipolar switching steps from positive to negative switching can be avoided. By stretching the gradient-moments as much as possible, and by minimizing the slew rates, acoustic noise as well as potential vibration could be reduced greatly. Moreover, specifically for TSE sequences, making use of parallel acquisition techniques such as GRAPPA[4] within the same total acquisition time allows the lengthening of the inter-echo spacing for the same acquisition time which stretches the gradient moments even further. A schematic diagram of gradient wave form optimization is illustrated in figure 1. As long as timing permits, the lowest gradient slew rate should be used. As a trade-off, for instance, the readout gradient amplitude could be slightly increased, i.e. the readout BW increased. In our work, it is about 10% higher.

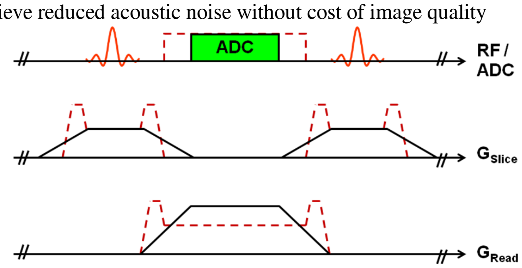

Figure 1: Comparison of conventional sequence (dashed lines) with quiet sequence (solid lines). The reduction of ADC represents a 10% increase of bandwidth.

METHODS: This concept is implemented in two basic sequences, 2D TSE (Turbo-Spin-Echo) and 2D/3D GRE (Gradient Recalled Echo) sequences which compose variety of clinical protocols, covering neuro, spine and MSK applications. Using these protocols, in-vivo studies were performed on Siemens 1.5T MR scanners (Espree, Avanto) and a 3.0T MR scanner (Verio) with healthy volunteers and patients (consent was obtained previous to study).A total of 10different studies were performed , each comparing standard clinical protocols with the corresponding quiet protocol. The image resolution was identical for all protocols. The readout BW of quiet protocols both based on GRE and TSE was about 10% higher than standard clinical protocols. Specifically, and only for TSE based protocols, TR and TE were respectively modified from 5000 and 93ms to 5180 and 85ms to accommodate for inter-echo spacing. In addition, GRAPPA was used in TSE based protocols with a reduction factor of 2, in order to halve the echo train length and relax the inter-echo spacing, which results in further reduction of acoustic noise at the expense of SNR.
The studies included the imaging of head, L-spine and knee anatomies.
The difference of total imaging time never exceeded 2% for TSE based protocols. The average and peak dB value of acoustic noise during each sequence was measured using an iPhone 4S (Apple Inc.) with a linear recording range of 40-100dB, placed within the scanner room beyond the 5 Gauss line. The following image quality assessment experiment was performed : 54 random pairs of T2w TSE images acquired with the reference, quiet and quiet with GRAPPA protocols where displayed to 2 trained radiologists, who then rated the quality of the right image over the left image from -10 to +10, with a positive score indicating the superiority of the right image.

Protocol	acoustic noise – avg./peak (dB)		
	reference	quiet	quiet with GRAPPA
Environment	57/65		
T2w 2D GRE	90/97	81/87	
T1w 3D GRE	90/97	74/81	
T2-SWI 3D GRE	87/95	75/81	
T2w TSE	82/89	77/86	69/78
FLAIR	85/92	73/82	74/83

Table 1: Average and peak dB comparison between reference and quiet version of clinical protocol.

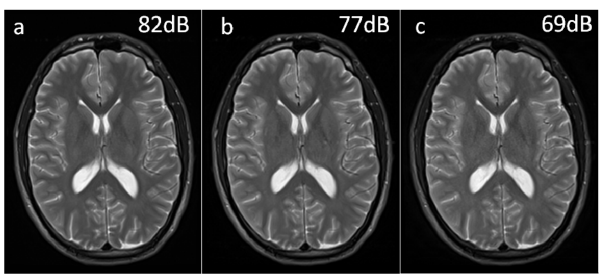

Figure 2: a. standard clinical protocol, TR/Te = 5000/93 ms, BW = 107 Hz/ pixel, Acq. time=1'37" **b.** qTSE protocol, TR/TE = 5180 / 85 ms, BW = 125 Hz/ pixel, Acq. time = 1'40" **c.** same as b, with GRAPPA R=2. Average acoustic noise shown as inset.

left image \ right image	reference	quiet	quiet w/ GRAPPA
reference	-0.4	-0.8	-3.8
quiet	2.3	1.0	-1.5
quiet w/ GRAPPA	2.3	3.0	0

Table 2: Average radiologist scores comparing image quality of reference and modified T2w TSE. Positive score show preference of the right image over the left image, on a -10 to +10 scale.

RESULTS: All dB measurements are displayed in Table 1. Significant acoustic noise reduction was achieved, especially for the TSE based protocols. The quiet version of each sequence offered a consistent reduction of noise level with a mean average/peak reduction of 10.8/10.6 dB. The use of GRAPPA in quiet sequences further reduced acoustic noise by 8/8dB for the TSE sequence, at the expense of comparative degradation of image quality. The radiologist scoring for the T2w TSE images are displayed in table 2. Without use of Parallel Imaging, the perceived quality difference between images obtained with quiet andstandard clinical sequences fell within the bounds of perceived difference between 2 identical images with a 90% confidence interval. An example of image comparison is given in figure 2.

DISCUSSION: Quiet modified sequences allow on average for more than a factor 10 reduction in noise, without significant degradation of image quality or imaging time. In the case of TSE, use of Parallel Imaging can even further reduce acoustic noise.

CONCLUSION: This study demonstrates that simple gradient modifications can be applied to several standard clinical protocols to achieve over a factor 10 reduction of acoustic noise, for an improved patient comfort without cost of image quality, imaging time, or hardware modifications.

REFERENCES: [1]. Cho at al, ISMRM 1998; [2]. Hennel F. et al. MRM 1999 Jul 42(1):6-10; [3]Witzel et al, Methods for functional brain imaging, thesis, MIT division of Health Sciences and Technology; [4] Griswold MA et al. MRM 2002

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