Improving EPI Imaging Quality and Sound Levels with Bandwidth Selection

K. McMahon[1], A. Pringle[1], M. Eastburn[1], D. Maillet[1]

[1]Centre for Magnetic Resonance, University of Queensland, Brisbane, Queensland, Australia

Introduction:

Echo planar imaging (EPI) is a rapid sequence that has been applied with great success to diffusion, perfusion and functional magnetic resonance imaging (fMRI) of the brain. However, the oscillating gradients in EPI can produce artefacts such as Nyquist or N/2 ghosting, plus they generate a high level of acoustic noise. Nyquist ghosting is the result of a time shift between the odd and even echoes produced by oscillating readout gradients. Each alternate echo has to be time-reversed before Fourier transformation, and any misalignment or shape asymmetry results in ghosting in the reconstructed image, typically a ghost half the field of view away from the main image in the phase encoding direction. Where the image and Nyquist ghost overlaps, interference patterns are generated and signal to noise is lost. In fMRI, activation data from these regions becomes ambiguous. Misalignment of alternate echoes can be addressed by adjusting the timing of digitization, adjusting the gradients or postprocessing with the aid of reference scans[1,2], but these are not effective in removing shape asymmetry, which is the result of time-reversal asymmetry in the gradient waveform caused by eddy currents and static magnetic field inhomogenieties.

The combination of currents within the gradient coils (or eddy currents within conductive structures) and the static magnetic field evokes Lorentz forces, which in turn induces vibrations within the gradients and other structures, which couple to the surrounding air to generate noise.[3,4] The rapid gradient switching in EPI induces large Lorentz forces, which increases with field strength and gradient current.[4] Apart from concerns of patient comfort and safety, the intense noise generated with EPI can evoke spurious fMRI signal in various areas of the brain[5,6,7] and hampers delivery of acoustic stimuli and overt vocal response. The effect of the switching frequency of the readout gradient upon acoustic noise levels has been investigated for gradient echo EPI at 4T.[8,9] Acoustic sound levels can be minimized by appropriate choice of bandwidth, however nothing has been reported about corresponding effects on Nyquist ghosting. Maximum bandwidth is desirable in EPI to reduce echo spacing and geometric distortions. Although low bandwidths generate low noise and low Nyquist ghosting, using a higher bandwidth, which provides minimum ghosting and noise, is a superior alternative. The relationship between frequency of readout and Nyquist ghosting plus acoustic noise was investigated at 1.5 and 4T systems, with identical Sonata gradients.

Methods

Images were taken with a Bruker Medspec S400 system operating at 4T and Siemens Sonata 1.5T system, both with Sonata gradients (maximum gradient 40mT/m, 200mT/m/s slew rate). On the 4T, a transverse electromagnetic (TEM) head coil was used for radiofrequency transmission and reception [10]. A head array coil was used for RF reception on the 1.5T system. Both systems were run with Siemens consoles and software. The effect of different bandwidths on image quality and sound was investigated using gradient echo EPI sequences at both field strengths. Due to increased flow contribution at 4T, gradient echo EPI including small diffusion gradients was also investigated. Other imaging parameters include; matrix 64x64, FOV 23cm, 21x5mm slices, 10% gap, TR 2.1s, TE 30ms, or 47ms when diffusion gradients were included, where b was 100s/mm^2. The signal of the Nyquist ghost (excluding the areas of interference) was measured across all slices, for each bandwidth. A-weighted sound pressure levels (SPL) were measured with a Bruel and Kjaer sound level meter at the foot of the bed, approximately 2.2m from the centre of the magnet for both systems. An MR compatible microphone was also placed in the centre of the bore to obtain recordings.

Results and Discussion

The average signal to noise ratios from the Nyquist ghost at different bandwidths is plotted below (Fig 1+2). It is obvious from the graphs that there are bandwidths that should be avoided, as well as those that offer minimal ghost interference. These minimums are not consistent across different field strengths. The Nyquist ghosts are more prominent at higher field, as expected. The BOLD weighted and BOLD plus diffusion gradients at 4T are very similar except above 3250 Hz/pixel. The diffusion gradients attenuate the image signal, so the Nyquist ghost is relatively lower. The sound levels are greater overall at higher field strength, in keeping with other reports within the literature. At 1.5T, a variance of 9.7 dB in SPL was possible depending upon selection of sequence bandwidth. A 6dB and 7.6dB variance was measured for BOLD and BOLD plus diffusion, respectively, at 4T. Both BOLD and BOLD plus diffusion sequences at high field show similar trends below 3256Hz/pixel, although with diffusion gradients added, sound levels are 2.1dB lower overall. At 4T, the bandwidths that show severe ghosting also have increased sound levels. This raises the possibility that increased eddy currents are generating more movement among the gradient and magnet structures and hence more sound. However, the acoustic network within each system is complicated, and eddy currents could be generating harmonics which cancel with the major sound frequencies. For example, at 1.5T and a bandwidth of 2250 Hz/pixel, there is increased ghosting but the lowest sound level. This work has shown that it is possible to obtain minimum ghosting and noise levels for gradient echo EPI for a given system: at bandwidths of 2005 Hz/pixel at 1.5T and 2230Hz/pixel for 4T, with either sequence.

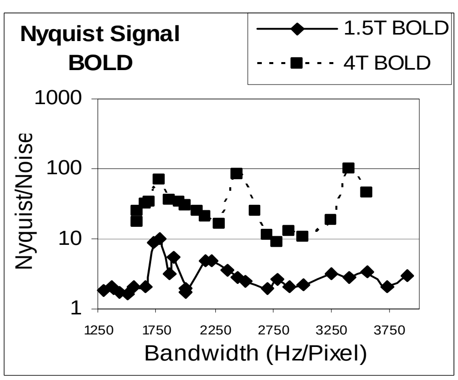

Fig. 1: Nyquist signal to noise ratios at 4T and 1.5T for GE-EPI. (Nyquist/Noise in logarithmic scale.

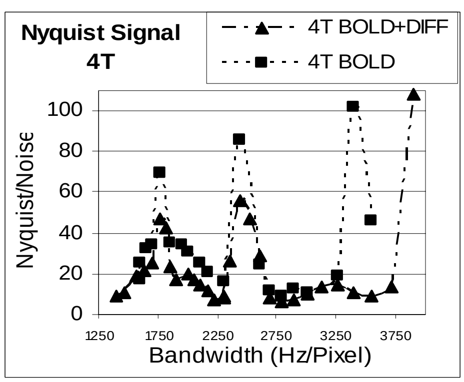

Fig. 2: Comparison of ghost intensity with BOLD and BOLD plus diffusion gradients at 4T.

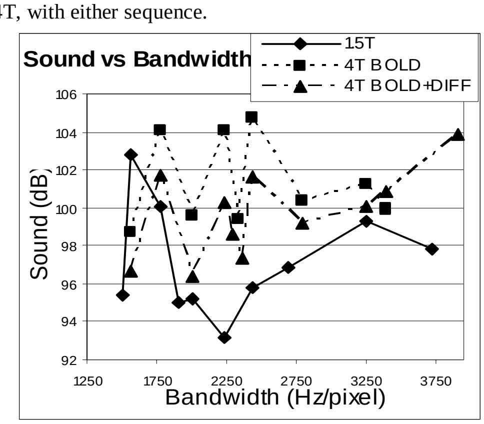

Fig. 3: Sound levels in dB at different bandwidths for all three sequences.

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