Towards the accurate and precise assessment of SNR in vivo at 7T

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Introduction

The signal-to-noise ratio (SNR) is a fundamental measure for the quantification, comparison and optimization of image quality and MRI system performance. High resolution reference SNR-maps can be obtained using the 'multiple acquisitions' technique, where the mean of repeated acquisitions is divided by the standard deviation on a pixel-by-pixel basis. This, however, is time-consuming (requiring typically 30-300 repeats [1]) and thus also highly sensitive to motion *in vivo*. An alternative strategy is to approximate the image statistics within regions of interest (ROIs) using single or paired measurements. The 'difference method' [2], estimates signal and noise levels within an ROI from the sum and the difference of two identical acquisitions respectively. The ability to estimate both these components at the same spatial location, and the good concordance of results with the multiple acquisition technique [3] has made the difference method a prevalent way of measuring SNR for *in vivo* applications where a homogenous thermal noise distribution cannot be assumed (i.e. when employing parallel imaging, multichannel coils or reconstruction filters). At 7 Tesla, and particularly when using high SENSE factors, difference images of single shot (ssh) Echo Planar Imaging (EPI) acquisitions were observed to contain localized structured components dominating the thermal noise signal (Figure 1). This makes the reliable quantification of SNR difficult. The apparent absence of such artifacts in phantom scans suggests they may be the result of head movement and cardiac-/respiratory cycles which due to their transient nature survive the subtraction process. In this investigation the precision and accuracy of an alternative SNR measurement technique, comprising separate signal and thermal noise-only (no RF excitation, no gradients) acquisitions [5], henceforth referred to as the NEMA (National Electrical Manufacturers Association) method is evaluated, and compared to the difference and the multiple acquisition methods.

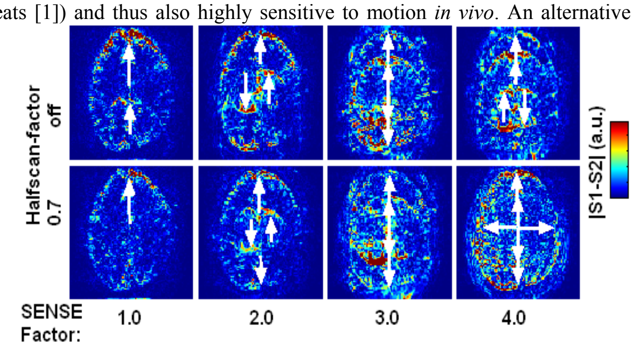

Figure 1: Illustration of subtraction images of two identical single shot spin echo EPI acquisitions at 7T: structured differences (arrows) dominate the thermal noise profile.

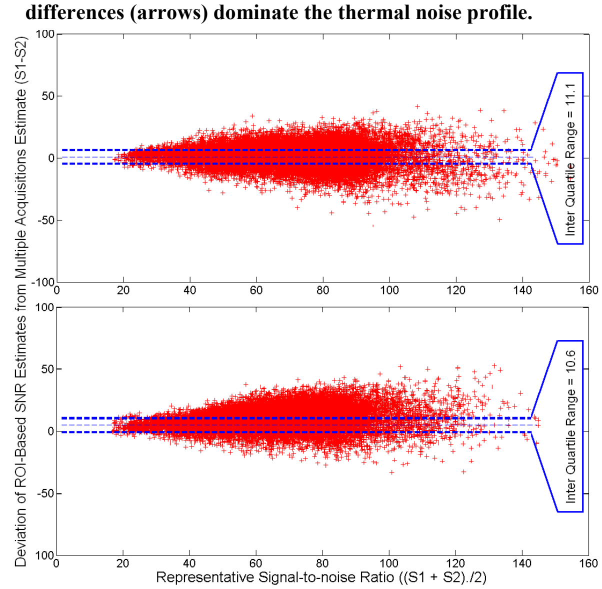

Figure 2: Bland-Altman plots comparing the Difference vs. multiple acquisition methods (top) and NEMA vs. multiple acquisition methods (bottom) SNR measurements. S1 represents the multiple acquisition technique.

Methods

Experimental setup: to determine the attainable accuracy and precision of SNR measurement techniques in absence of motion, measurements were performed on a phantom (diameter 20cm, containing 2% Agar) using a 7 Tesla Philips Achieva scanner and 16-channel head coil. The acquisition sequence comprised an ssh spin echo EPI sequence with TE/TR = 60ms/10000ms, SENSE reduction factor = 2 and a half-scan factor = 0.7. 35 slices were scanned with a FOV = 192x192 mm^2 and voxel size 2x2x2 mm^3.

Datasets: Three types of SNR measurement were performed: (i) ***Multiple acquisition technique*****:** a data-set comprising 100 acquisition-repeats. The first 6 repeats were discarded to ensure steady state had been reached. (ii) ***Difference method:*** a data-set comprising 3 dynamic repeats with the first scan discarded as a dummy scan to ensure full T1 recovery. (iii) ***NEMA method***: also comprising 3 dynamic acquisitions with the first one again being discarded. The second acquisition was used to estimate the signal intensity, and the third one was a thermal noise-only acquisition. All images were recorded as magnitude images. FSL FLIRT [4] motion correction was used to reduce the effects of scanner drift.

Data Analysis: ROI-based SNR calculations were performed within neighbourhoods spanning 5x5x5 voxels, and values were allocated to the central voxel. To allow the evaluation of the measurement precision, the SNR was calculated in this way for each voxel of a volume of 32x32x20 voxels at the centre of the phantom. SNR calculations for the multiple acquisition and difference methods were performed as described in [3]. For the NEMA method, the noise within a neighbourhood was estimated using the assumption that noise follows a Gaussian distribution with zero mean [6]:

$$\sigma_{NoiseImage} = \sqrt{\frac{\sum_{i,j,l} x^2(i,j,l)}{N}}$$

Where: i,j, l: are the voxel coordinates
x: is the noise image
N: number of neighbourhood voxels

Results

Bland-Altman plots were used for a voxel-by-voxel comparison of the difference and NEMA methods to the reference multiple acquisition measurements (Figure 2). To quantify measurement precision and accuracy, the inter-quartile range and median were calculated for both plots and values listed on the graphs. The precision achieved by both the NEMA and difference methods were found to be observed to be comparable, while the NEMA results appear to be slightly biased towards lower values.

Discussion

Techniques employing repeated acquisitions for the extraction of SNR image statistics (e.g. difference method, multiple acquisitions method) tend to assume that differences between repeats induced by sources other than random noise are negligible. In this investigation the widely used difference method was found to not be adequate for the characterization of random thermal noise at high field strengths in presence of typical *in vivo* motion. Factors that may potentially contribute to the apparent increase in sensitivity to motion at 7T may include: (i) the technically challenging environment posed by ultra high magnetic field leading to more severe reconstruction artifacts; (ii) the intrinsically higher SNR levels at ultra high field may result in relatively small differences of reconstructed images to be of relevant proportions in the difference images approximating thermal noise. Since the NEMA method obtains the noise image estimate from a single dedicated acquisition, it does not suffer such artifacts. Figure 2 illustrates that in absence of motion (using phantom scans) the precision of the difference and NEMA methods are comparable allowing the latter to be considered a more robust alternative technique for *in vivo* measurements.

References

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