Array coil signal-to-noise ratio measurement: a comparison of methods

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Introduction

Signal-to-noise ratio (SNR = η/σ) is a key image quality metric but is not always straightforward to evaluate due to the difficulties in accurately estimating the noise level in an image. There are multiple approaches[1,2,3], using a single image, more than one image and noise-only acquisitions. Previous work[1] has compared several methods but not included the noise-only methods. The aim of this phantom study was to compare a wider range of SNR measurement methods.

Materials and Methods

A 17cm diameter spherical phantom was imaged using two identical eight-channel head arrays (referred to as A and B) in the same 1.5T whole-body system (Signa Excite, GE Healthcare, Waukesha, WI) using a fast gradient echo sequence (TR/TE = 12.2/5.7ms, ±31.25kHz receive BW, 512x512 matrix size, 250mm FOV, 3mm slice thickness). These parameters ensured a high enough SNR (≈20) to avoid noise bias in determining η [4]. The raw data were collected and used to reconstruct images using the standard root-sum-of-squares algorithm[5] and the SNR units reconstruction method[2]. Regions of interest (ROIs) of diameter 34mm were placed automatically 1.2mm from the edge of the phantom with their azimuthal locations corresponding to the individual coil elements. Azimuthally matched noise ROIs were placed 3.4mm outside the phantom. The noise in each signal-containing ROI was assessed using five methods: a multiple image acquisition to evaluate the mean pixel-wise standard deviation (SNR_{mult}); the two-sequential-image difference method (SNR_{diff}); a noise-only image acquired with the RF amplifier output switched off (SNR_{norf}), which includes the following correction factor[3,4]

$$\kappa = \frac{1}{\sqrt{2n - \beta(n)^2}} \quad \text{where} \quad \beta(n) = \sqrt{\frac{\pi}{2}}\,\frac{(2n-1)!!}{2^{n-1}(n-1)!}$$

for the magnitude reconstruction of the Gaussian noise; the same noise-only image used to evaluate the noise power (SNR_{pow}): $\langle N^2 \rangle = 2n\sigma^2$, where N is the noise pixel intensity and n is the number of elements in the array (8 in this case)[3]; and the SNR units reconstruction (SNR_{units}). In addition, a single-image method using the standard deviation of the signal in the noise ROIs was used, including the same magnitude-data correction factor as SNR_{norf} (SNR_{std}). SNR_{mult} was used as the gold standard for comparison, as in previous studies[1,2].

Results

The various measurements of the SNR agreed well, to within 10%, for array A (Figure 1). However, this was not replicated for array B, with SNR_{norf} and SNR_{std} approximately equal but yielding values up to 51% lower, and SNR_{units} values up to 89% higher, than SNR_{mult} (Figure 2a). Inspection of the noise covariance matrix of array B (Figures 2b&c) revealed significant resistive and inductive coupling between the elements such that, while the coil still passed the manufacturer's QA tests, the statistical distribution of noise was no longer the expected χ-distribution with $2n$ degrees of freedom, making the usual magnitude-data correction factor incorrect. SNR_{pow}, averaged across the eight elements, agreed well with SNR_{mult} due to its insensitivity to noise correlations, but lacked the spatial discrimination of SNR_{mult} and SNR_{diff}, which clearly indicated the coil elements with worse performance. SNR_{units} was a marked overestimation of the true SNR, although the reason for this is unclear.

Conclusions

The SNR measured by all the methods considered here is very consistent in coils without significant coupling between elements demonstrated in the noise covariance matrix. However, once coupling between elements is present, the equivalence of the measures breaks down such that the only single-image method that agrees with the gold standard is $SNR_{pow} = \eta\sqrt{(2n/\langle N^2 \rangle)}$. The inter-element coupling disrupts the statistical assumptions upon which SNR_{std} and SNR_{norf} rely, so that in the absence of longitudinal SNR data, a difference of >20% between SNR_{std} or SNR_{norf} and SNR_{pow} can provide evidence of array failure. In this situation SNR_{pow} provides the most accurate estimate of the underlying SNR in a single image acquisition. SNR_{pow} will also be useful in clinical applications: the presence of a patient in the array introduces noise correlations but the noise power method enables accurate SNR measurements even in a single image.

[1]Dietrich, O. et al. J. Magn. Reson. Imaging **26**, 375–385 (2007); [2]Kellman, P. & E. R. McVeigh. Magn. Reson. Med. **54**, 1439–1447 (2005);
[3]Constantinides, C. D., E. Atalar & E. R. McVeigh. Magn. Reson. Med. **38**, 852–857 (1997); [4]Koay, C. G. & P. J. Basser. J. Magn. Reson. **179**, 317–322 (2006);
[5]Roemer, P. B. et al. Magn. Reson. Med. **16**, 192–225 (1990).

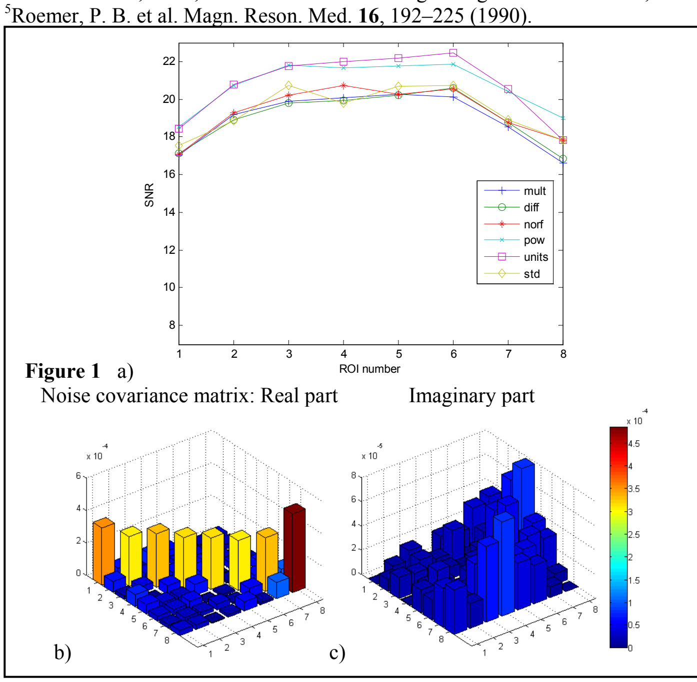

Figure 1 a)
Noise covariance matrix: Real part   Imaginary part
b)   c)

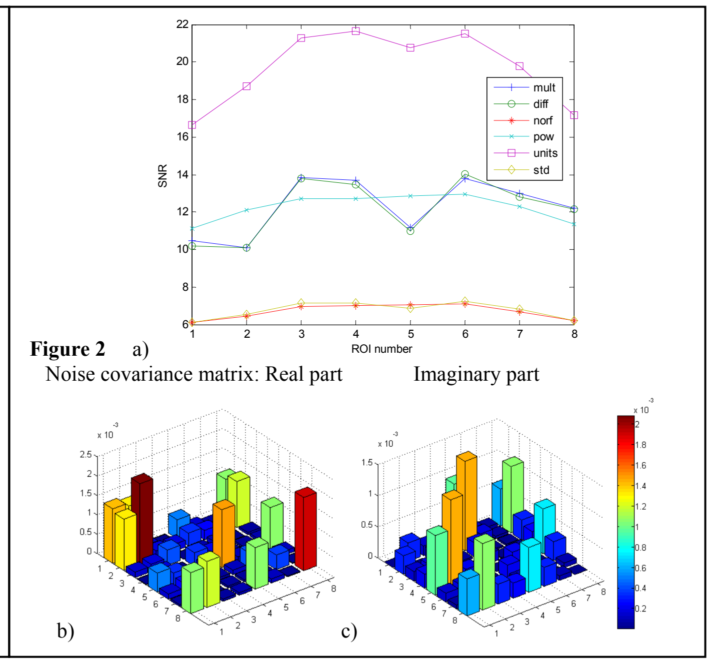

Figure 2 a)
Noise covariance matrix: Real part   Imaginary part
b)   c)