Noise characteristics in MRI with multi-channel arrays, parallel imaging, and reconstruction filters

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Introduction: Conventional MRI with a single-channel RF coil and image reconstruction by Fourier transform followed by magnitude calculation results in spatially homogeneously distributed image noise with a Rayleigh statistics in background areas (i.e. in air). The statistical properties of this background noise are frequently used to derive the noise level in foreground areas of the image, e.g. to determine the signal-to-noise ratio (SNR) [1]. The purpose of our study was to analyze the statistical noise distribution in background areas of MR magnitude images for current state-of-the-art techniques such as data acquisition by multi-channel coil arrays, parallel imaging, and application of different reconstruction filters.

Materials and Methods: Phantom experiments were performed on a 1.5-T whole-body MRI system (Magnetom Sonata, Siemens Medical Solutions, Erlangen, Germany) with a single-channel (1CH) and an 8-channel (8CH) receiver coil system without parallel imaging, with the GRAPPA algorithm, and with a modified SENSE technique (mSENSE). A half-Fourier RARE (hf-RARE), an SSFP, and an EPI sequence were used for image acquisition. Five different reconstructions were compared for all setups: image reconstruction without additional filter, with Hanning filter, with large-field-of-view (FOV) correction, with intensity normalization, and with elliptical rawdata filtering. Intensity histograms based on the signal distribution in a background region (size 64×16 pixels, close to the image edge in readout direction) were used to evaluate the noise characteristics. We compared the histogram data with the conventionally expected Rayleigh distribution [2], with a Gaussian distribution (for the hF-RARE sequence), and with the non-central chi-distribution [3] in the 8-channel acquisitions without parallel imaging and with GRAPPA.

Results: Background noise of the EPI measurements with the 1CH coil agrees very well with the Rayleigh statistics (Fig. 1, middle row, left diagram); applying reconstruction filters changes only the width of the Rayleigh distribution (Fig. 1, bottom row). EPI measurements with the 8CH coil show different noise distributions depending on the application of parallel imaging: without acceleration, i.e. after sum-of-squares reconstruction, or with GRAPPA, a non-central chi-distribution was found, while mSENSE resulted in background noise with Rayleigh distribution (Fig. 1, middle row). Results of the SSFP acquisition were very similar to those of the EPI measurements. In contrast, background noise of the hf-RARE acquisition (based on a real-part reconstruction after phase correction) could be approximated by a Gaussian distribution (Fig. 1, top row), either with mean value 0 (1CH and mSENSE acquisition) or with a mean value greater than zero (8CH sum-of-squares reconstruction, GRAPPA). Spatial inhomogeneity of the noise distribution (e.g. due to g-factor effects) was not analyzed in this study.

Conclusions: The statistical signal distribution of background noise varies substantially depending on the pulse sequence type, the number of receiver channels, and the chosen parallel-imaging technique. This must be taken into account, if mean values or standard deviations of background noise are employed e.g. for SNR or CNR calculations. Assuming a Rayleigh distribution as in conventional MRI will generally yield invalid results.

References: [1] Kaufman L, Kramer DM, Crooks LE, Ortendahl DA. Radiology 1989; 173:265–267. [2] Edelstein WA, Bottomley PA, Pfeifer LM. Med Phys 1984; 11:180–185. [3] Constantinides CD, Atalar E, McVeigh ER. Magn Reson Med 1997; 38:852–857.

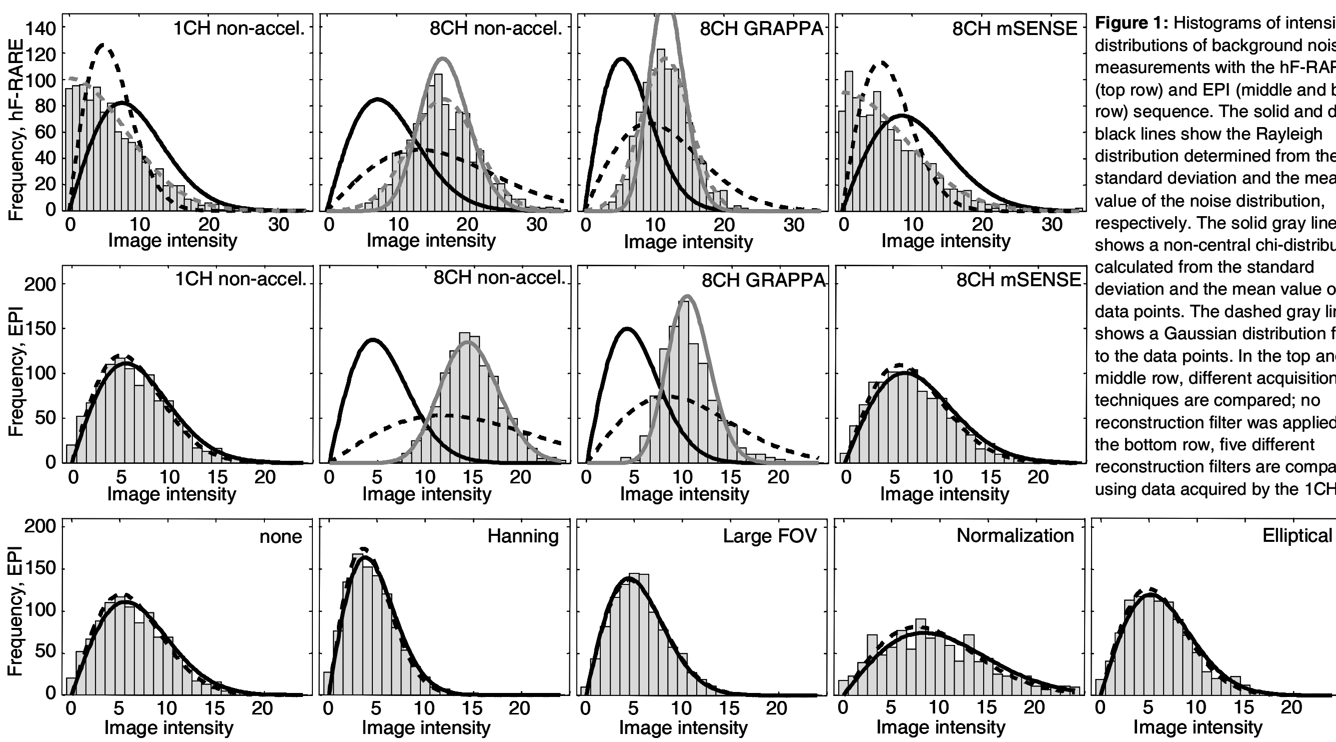

Figure 1: Histograms of intensity distributions of background noise in measurements with the hF-RARE (top row) and EPI (middle and bottom row) sequence. The solid and dashed black lines show the Rayleigh distribution determined from the standard deviation and the mean value of the noise distribution, respectively. The solid gray line shows a non-central chi-distribution calculated from the standard deviation and the mean value of the data points. The dashed gray line shows a Gaussian distribution fitted to the data points. In the top and middle row, different acquisition techniques are compared; no reconstruction filter was applied. In the bottom row, five different reconstruction filters are compared using data acquired by the 1CH coil.