Introduction

Recently, a de-noising technique referred to as ‘AWESOME’ has been proposed that reduces noise by averaging of complex data in wavelet space. It permits to use an image series acquired with varying contrast as input without the need for repeated acquisitions. Application to relaxation studies and diffusion-weighted MRI experiments demonstrated that quantitative information is well preserved in the de-noised images while object features initially covered by noise are regained. Here, we investigate a novel application of the AWESOME algorithm to denoise high-resolution 3D gradient-echo (GRE) EPI and 3D VASO time series used for BOLD and cerebral blood volume weighted fMRI.  

Methods

- Two datasets acquired at 7T (MAGNETOM 7T; Siemens Healthcare, Germany), 32-channel head coil (Nova Medical, Wilmington, MA, USA):  
  i) Resting-state BOLD-based fMRI data, 3D GRE-EPI scans in healthy subject: 1.5x1.5mm in-plane resolution, 0.25/0.5/1/2mm slice thickness, 12 slices, TR=3s, TE=22ms, in-plane GRAPPA 2, 30 repetitions 
  ii) Task-based fMRI data: CBV and BOLD contrasts were recorded, 3D slice-saturation slab-inversion VASO (55-VASO) sequence: 0.75x0.75mm in-plane resolution, 1.8mm slice thickness, 8 slices, TR=3s, TE=22ms, in-plane GRAPPA 2  
- Paradigm: unilateral finger-tapping task (block design: 1.5min total acquisition time).

Wavelet classification & extraction of signal-dominated coefficients

Averaging & rescaling according to contribution probability

Merging of signal-dominated and rescaled coefficients

Wavelet transform & post-processing

High SNR complex image series

Low SNR complex image series

Pre-processing & wavelet transform

Wavelet classification & extraction of signal-dominated coefficients

Averaging & rescaling according to contribution probability

Merging of signal-dominated and rescaled coefficients

Wavelet transform & post-processing

High SNR complex image series

Pre-processing: motion correction, background phase correction via a total variation based algorithm, noise-level normalization by noise estimation from 1D wavelet transformation of the time line for each voxel. 

AWESOME-2 algorithm modification: The magnitude estimation was modified to compensate for non-zero phase variation of signals (despite phase correction). Estimation of the magnitude correction is performed by analyzing the probability distribution of ideal signals (varying in phase by measured phase variation for each time line), superimposed with white noise. The modification can be applied to all or just rescaled wavelet coefficients by user choice. 

AWESOME de-noising parameters are determined via global optimization, reducing the mean-squared difference of denoised output images to a high-SNR target version of the same images. 

Goal: A target image is obtained via simulation of equivalent measurements by artificial neural network (ANN) driven approximation of the current measurements. 

ANNs are trained to estimate the voxel-wise intensity changes over the image series by learning the underlying behavior from randomly selected voxels. Noise is not reproducible by ANNs, yielding a smooth approximation of the mean images. 

Simulated "noisy" measurements for AWESOME optimization are obtained by adding complex white noise to the noise-free simulations.

Conclusions

The multi-contrast data suggest that the de-noising preserves the temporal and spatial signature of "true" activation while reducing false positives. In conclusion, application of AWESOME to fMRI may offer the potential to produce meaningful results from lower SNR data, such as acquisitions at very high resolutions or with reduced paradigm length.

References


Acknowledgements

This work was funded through the Helmholtz Alliance ICEMEd. Laurentius Huber is supported by the American NIMH Intramural Research Program.