Catching Physiological Noise: Comparison of DRIFTER in Image and *k*-Space

Arno Solin[1], Simo Särkkä[1], Aapo Nummenmaa[2], Aki Vehtari[1], Toni Auranen[3], and Fa-Hsuan Lin[1,4]
[1]*Department of Biomedical Engineering and Computational Science, Aalto University, Espoo, Finland,* [2]*Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Boston, MA, United States,* [3]*Advanced Magnetic Imaging Centre, Aalto NeuroImaging, Aalto University, Espoo, Finland,* [4]*Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan*

TARGET AUDIENCE

The results presented in this work are of interest to researchers interested in the effects and space–time distribution of physiological noise in fMRI in image and *k*-space, and to practitioners looking for possibilities of removing physiological noise in their functional MRI data.

PURPOSE

Accurate treatment of non-white noise sources in fMRI plays an important part in improving the signal-to-noise ratio of the data [1]. Oscillatory noise stemming from heartbeat and respiration induced movement and variation in blood flow can be effectively removed by using model-based methods [2, 3]. In practice, such structural noise is often removed by retrospective methods using only the reconstructed magnitude images provided by the scanner. Catching the noise components in *k*-space prior to reconstructing the image data can be beneficial. In this study we show that the DRIFTER [3] method can be extended to work with both *k*-space and complex image space data, which leads to more accurate treatment of noise.

METHODS

DRIFTER is a model-based method for retrospective estimation and removal of physiological noise. The method uses Bayesian optimal filtering methods, and it has shown excellent performance in comparison to other methods [3]. DRIFTER is capable of decomposing the fMRI data into additive components, which describe the oscillatory structured noises, the slow drift and the blood-oxygen-level dependent (BOLD) signal, and the unstructured residuals. We apply the DRIFTER method to the standard sum-of-squares (SoS) reconstruction (magnitude images), to the complex-valued reconstructed coil images, and to the raw *k*-space data before reconstruction. For the complex-valued data, the real and imaginary components were dealt with independently. For the reconstruction we used Kaiser–Bessel regridding [4, 5], and reconstructed images were similar to the images reconstructed by the scanner software. The final maps for the complex and *k*-space data were weighted by the coil images when summing over the channels (as in SoS reconstruction).

We used a 27-run set of resting state fMRI data and anatomical images for one volunteer obtained with a 3 T scanner (Siemens Skyra; 32-channel receive-only head-coil array). The EPI sequence parameters were TR: 77 ms; TE: 21 ms; FA: 60 degrees; FOV: 224 mm; matrix size: 64×64; and voxel size 3.5×3.5×6 mm. Each run, roughly 30 s in length, comprised of two slices; one fixed reference slice and the gap size between the slices advancing with run number. The cardiac and respiration reference signals were acquired time-locked to the fMRI data using peripheral (BIOPAC) pulse measure and a respiratory belt, respectively. The sampling frequency of the physiological signals was 1 kHz. We used two harmonic resonators in the DRIFTER algorithm, and their frequencies were estimated from the external cardiac and respiration signals for each run. The EPI trajectory parameters for the data were: ramp times: 140 μs, flat-top time: 220 μs, and ADC readout time: 409.6 μs.

RESULTS

We show cardiac noise amplitude maps for a set of selected slices in Fig. 1. The rows correspond to amplitudes estimated by DRIFTER in (i) magnitude only, (ii) complex image data, and (iii) *k*-space data. The comparison of the complex and magnitude image space data is more straightforward because DRIFTER deals with each voxel spatially independently, whereas in the *k*-space data, DRIFTER is independent over the *k*-space.

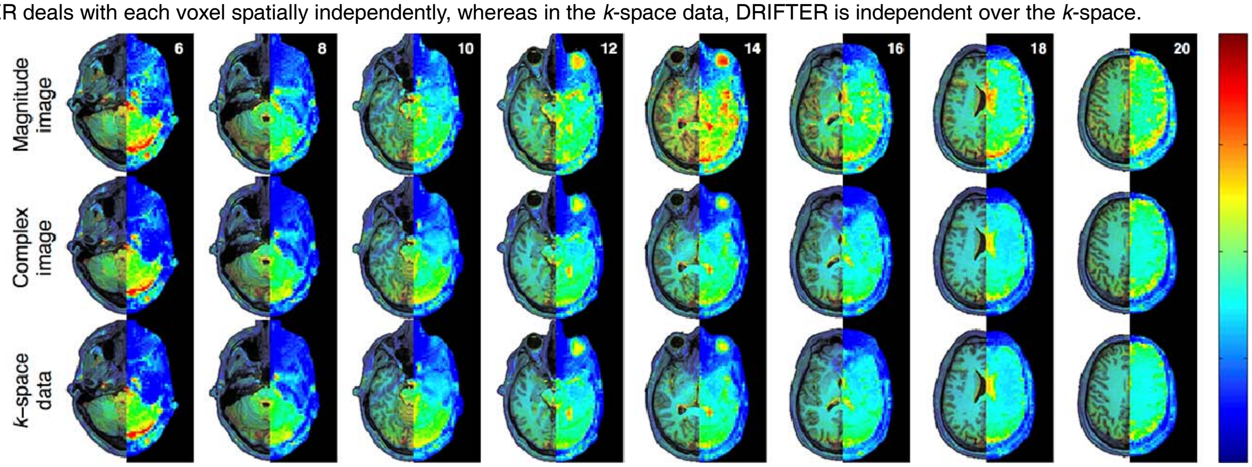

Figure 1. Cardiac noise amplitude maps reconstructed from the standard magnitude image data and compared to maps from complex coil image data, and *k*-space data. The noise magnitudes are logarithmic and may vary between the reconstruction methods.

DISCUSSION

As the components in DRIFTER are purely additive and the inverse Fourier transform reconstruction is a linear operation, the results should in theory be similar. The comparisons were done for the reconstructed noise amplitude maps, where we concentrated on the spatially more localized cardiac noise. The overall map structures agree with earlier results [6] and suggest that there are clear differences in the noise reconstruction between the magnitude images, and the complex image and *k*-space data. The latter ones are almost identical, the slight differences stem from the non-uniform sampling of the *k*-space. The results imply that the noise influence is clearly more localized in the complex and *k*-space maps, especially near the big arterial veins. This suggests that estimation and separation of the structured physiological noise should be done before the noise effects get aliased into the image data.

CONCLUSIONS

We have presented how the physiological noise removal method DRIFTER can be applied to complex-valued fMRI image data and raw *k*-space data. The DRIFTER toolbox for SPM8 and Matlab is available for download online.

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