Physiological Noise Reduction in fMRI Using Vessel Time-Series as Covariates in a General Linear Model

Torben E. Lund and Lars G. Hanson

Danish Research Center for MR, Hvidovre Hospital, Copenhagen, Denmark

Introduction: Using power-density spectra of fMRI-time-series, Weiskoff *et al.* [1] found non-white noise contributions at frequencies corresponding to respiration, cardiac pulsation and slow drifts. The experiments were carried out with TR=0.142s, where cardiac noise is critically sampled. Dagli *et al.*[2] showed that cardiac noise becomes problematic when heavily undersampled. Significant effects of cardiac related variability were found in 27.5 ± 8% of all brain voxels. Low-frequency noise can be avoided by proper paradigm construction and high-pass filtering, but the cardiac and respiratory induced noise may be aliased to the paradigm frequency when the noise is not critically sampled. Non critically sampled physiological noise is normally present in fMRI, and the extra noise compromise the reliability of the activation maps. Here we present a method for physiological noise correction which requires no additional monitoring/sampling of physiological covariates as is the case for other methods [3, 4]. Unlike the method described in [5] it does not rely on *a priori* knowledge about truly activated voxels. Our approach resembles that suggested by *Petersen et al.* [6], except more anatomical *a priori* knowledge is used for locating voxel time-series dominated by respiratory and cardiac related noise. These time-series are then included as nuisance covariates in a general linear model.

Methods: In fig. 1, a standard-deviation (STD) image is shown together with the corresponding angiogram. Apart from edge regions, which are known to be associated with low-frequency noise [7], high STD is found in ventricles and regions with vessels visible in the phase-mapping angiogram. These regions are unlikely to be associated with neural activity, and their time-series could provide information of physiologically induced noise. For this experiment we selected five pixels with high STD located in the proximity of vessels or in ventricles, – the locations are shown as white arrows in fig. 1. The corresponding time-series were included as nuisance covariates in a general linear model, together with the paradigm boxcar convolved with a haemodynamic response function.

A set of 840 T_2^*-weighted MR images of a single slice oriented along *Sulcus calcarinus*, was acquired using a 1.5T Siemens Vision scanner (TR=0.2s, TE=66ms). Visual stimulation (alternating checkerboard) was applied in a boxcar paradigm of period, T_{paradigm} = 40s. Cardiac pulse and respiration was monitored. A realistic worst case dataset of images with cardiac noise close to the paradigm frequency was constructed by taking out every eighth of the 840 images, giving a set of 105 images with TR=1.6s, typical of activation studies. The 840 original images were used for constructing a "ground truth" activation image with no cardiac induced noise, and only little respiratory induced noise, against which the noise correction method could be tested. The two datasets were realigned, smoothed (FWHM=5.7mm) and analyzed in SPM99 (Functional Imaging Laboratory, Institute of Neurology, London). For the 840 images a simple design matrix i.e. the paradigm boxcar convolved with a haemodynamic response function, and high-pass filtering, was used. The 105 images were temporally bandpass filtered and were analysed using both a simple and a 5 nuisance covariate design matrix.

Results: Fig. 2 shows activation images and the design matrix containing the nuisance parameters. Using the more complex noise model, contrast loss due to physiological noise at the paradigm frequency was recovered.

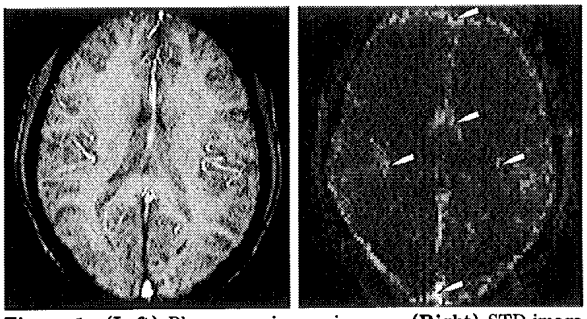

Figure 1: (Left) Phase mapping angiogram. **(Right)** STD-image of 105 images shown in logarithmic colormap. High STD is observed in edge-regions, ventricles and in areas in the proximity of a vessel. The arrows indicate voxels from which time-series were included in the model.

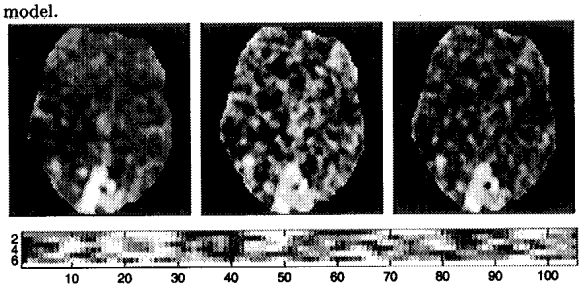

Figure 2: (Left) Activation image (SPM(T)) derived from the original 840 images collected at TR=0.2s, using a simple design-matrix. **(Middle)** Activation image (SPM(T)) derived from every eighth image of the 840 images, using a simple design-matrix. **(Right)** Activation image (SPM(T)) derived from the same 105 images analyzed using a complex design-matrix (shown at the bottom) containing vessel time-series. It is seen that the loss of contrast in the middle activation image can be recovered by applying the physiological covariates.

Discussion: Using STD-images it is possible to identify voxels located in vessels and ventricles. The inclusion of time-series from these regions as nuisance covariates in a general linear model enables modelling of non-white noise contributions. The method was validated using two datasets: one where cardiac noise was not problematic, and a subset of this where it was. The algorithm was demonstrated to recover the contrast losses due to physiological noise.

References

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