Sources and mitigation of physiological noise in brainstem fMRI studied at high resolution

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Introduction

Physiological noise is a potential major confound in brainstem fMRI. However, recently it was proposed that it may actually be spatially restricted to the region around to the brainstem [1,2,3]. Such restriction would greatly favor fMRI in this challenging region yet remains to be further verified. In this work, we utilize high resolution EPI of the brainstem to re-evaluate the localization of physiological noise and test different post-processing methods on its spatial distribution to maximize the temporal Signal-to-Noise Ratio (tSNR). Data is presented that explicitly supports the hypothesis: it is shown that on high-resolution data the physiological confounders can be reliably localized. We show that data masking based on CSF and cardiac regressors prior to data smoothing enhances the tSNR in the brainstem.

Method

The voxels affected by cardiac and respiratory physiological confounders are identified using a general linear model (GLM) computed with 29 regressors of which 22 model physiological confounders. We evaluated the regressors three times: first on unsmoothed data (A), second on smoothed data (B), and finally on data smoothed after undergoing masking (C).

Imaging protocol: BOLD fMRI data from 7 healthy volunteers were acquired on a 3T Ingenia system (Philips Healthcare, Best, The Netherlands), with a 32-channel head coil. During 7 minutes, the volunteers were instructed to keep their eyes open, fixating a cross. Physiological recordings were taken with a pulse oximeter and a respiratory belt, logged at 500 Hz and time-locked during image acquisition. One session consisted of 140 volumes plus 3 dummy scans. The parameters were: TE 35 ms, TR 3000 ms, Flip angle 78°, SENSE factor 2.8, 1.25x1.25x1.25 mm, FOV 200x180 mm, 28 coronal slices, tilted to cover the brainstem.

Preprocessing: All datasets were realigned and re-sliced using SPM12b; the tSNR was computed first on the raw data – case (A). In case (B) the data were smoothed with a Gaussian kernel, (FWHM = 4 mm). In case (C) the data were masked and smoothed (same kernel); the mask was a combination of a CSF mask and masking the voxels being significant for the cardiac contrast.

Analysis: We first computed and compared the tSNR for (A), (B) and (C). Then, four sets of regressors were created: they were computed via RETROICOR [4,5] using Fourier expansions of different order for the estimated phases of cardiac pulsation (3rd order), respiration (4th order) and cardio-respiratory interactions (1st order) [1], Heart Rate Variability (HRV) and Respiratory Volume per Time (RVT). The corresponding confound regressors were created using the Matlab physIO Toolbox [6,7]. Six movement regressors were computed using SPM12b. We infer on the respective explained variance via F-contrast for 5 contrasts: contrast #1 includes the 6 cardiac regressors, contrast #2 the respiratory regressors, contrast #3 the 4 cardio-respiratory interaction terms, contrast #4 the HRV term, contrast #5 the RVT term.

Results

The results are presented for one slice of a representative volunteer. Fig. 1a-c shows the tSNR map for the three cases: unsmoothed, smoothed, and smoothed after masking. The white arrows point at a region where masking is beneficial. Fig. 1d-i shows the cardiac and respiratory regressors for unsmoothed, smoothed and smoothed-after-masking data in the coronal and sagittal planes. While cardiac regressors are widely spread and clearly affecting the brainstem (d-f), respiratory regressors are scattered and weakly affect it (g-i). For unsmoothed data (d,g) cardiac regressors are localized around to the brainstem. However for smoothed data (e,h) cardiac regressors spread onto the brainstem. After the masking procedure, the brainstem contamination by physiological noise is substantially reduced. Note that the F-value returns to a similar level as for unsmoothed data. Fig. 2a shows the mean image, the csf-cardiac mask (Fig.2b), and the maximum intensity projection of the ratio between tSNR of the smoothed after masking data and the unsmoothed data (Fig.2c). These data clearly indicate that the masking operation enhanced effective sensitivity in the brainstem region.

Conclusion

This work offers evidence in support of the hypothesis that sources of physiological noise are located primarily around rather than in the brainstem region. A new masking procedure improved the tSNR in the brainstem, especially close to major vessels and CSF flow. The procedure relied on high resolution images to prevent partial volume effects in the first place.

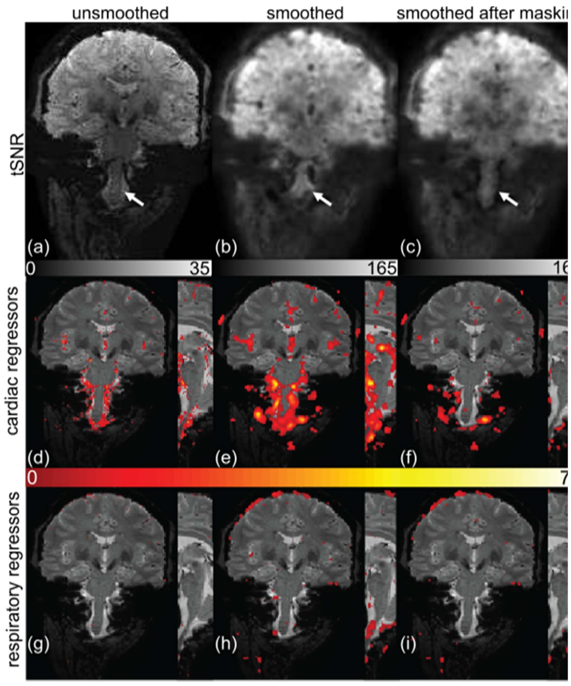

Fig.1: (a-c) show the tSNR for unsmoothed, smoothed and smoothed after masking data (same dataset and slice). (d-f) show cardiac regressors computed with a GLM for the same 3 cases. Cardiac regressors affect the brainstem region if smoothing is used without masking.

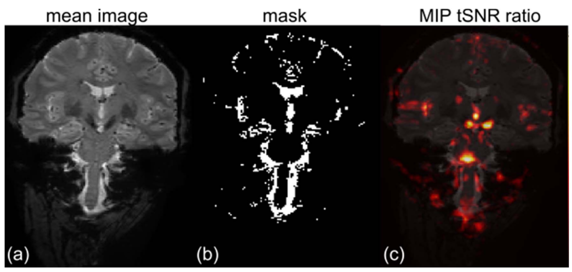

Fig.2: (a) is the mean image of the time series, (b) is the mask used in the preprocessing: a mask that includes both CSF and cardiac regressors masking, (c) in the ratio between the tSNR of the data after masking and smoothing and the tSNR of the smoothed data.

References

[1] Harvey et al. 2008 (JMRI), [2] Brooks et al. 2013 (fnhn), [3] Beissner et al. 2014 (Neuroimage), [4] Glover et al. 2000 (MRM), [5] Hutton et al. 2011 (Neuroimage), [6] Kasper et al 2009 (ISMRM), [7] open source code available as part of the TAPAS software collection: http://www.translationalneuromodeling.org/tapas/