Mitigation of Physiological Noise in the fMRI time-series by CSF Nulling

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Introduction:

Previous studies [1, 2] have shown that at high field strengths and lower resolutions, the temporal SNR of fMRI studies is dominated by the physiological noise, including respiratory and cardiac pulsations and 'BOLD-like' physiological noise. Further investigation has shown that the physiological noise is highly spatially correlated within gray matter and CSF, and that it is highest in CSF and significantly lower in the white matter [3]. At low spatial resolutions (e.g. 3mm) however, gray matter voxels are likely to be highly partial volume averaged with CSF, and thus CSF intensity fluctuations likely contribute to the noise seen in gray matter ROIs. The goal of this study is to reduce the physiological fluctuations in the resting brain gray matter regions as seen by conventional fMRI studies by eliminating the signal from CSF in the brain, especially within the sulci. To achieve this we employed an inversion recovery EPI acquisition. Our findings demonstrate that when the CSF is nulled, the noise in the fMRI time series of gray matter ROIs can be reduced compared to the normal EPI acquisition.

Methods:

Data from 11 healthy volunteers were acquired using a Siemens 3T Tim Trio system (Siemens Medical Solutions, Erlangen, Germany). To eliminate the CSF signal in the EPI scans, a slice-selective inversion recovery single shot gradient echo EPI sequence was used. The imaging parameters for the CSF-inverted data were TR=7000ms, TI=2300ms, TE=30ms, in-plane resolution 3x3mm^2, five 5mm thick slices with a 2mm slice gap and 60 time points. Single shot fully relaxed gradient echo EPI time-series were also collected in the resting brain at the same resolution, TR=5000ms, and TE=30ms. Automatic alignment protocols were used to ensure a standardized slice prescription in both acquisitions. Temporal SNR (tSNR) in the fMRI time-course was measured in ROIs defined in cortical gray matter on both the resting state scans and the CSF nulled images. In a given pixel the tSNR was determined from the mean pixel value across the 60 time points divided by its temporal standard deviation. Temporal standard deviation maps were generated to illustrate the spatial distribution of the physiological fluctuations across the brain for the two acquisitions.

Results:

Figure 1 illustrates the dependence of the physiological noise on the presence of CSF signal. Figures (A) and (B) are time course noise SD maps at the resting state with conventional acquisition whereas (C) and (D) show the standard deviation maps as they were derived from the CSF-inverted images. Table 1 shows the calculated gray matter tSNR, averaged over 10 ROIs, from each of the 11 subjects for the resting state scans and the CSF-inverted images. A moderate improvement of the tSNR was observed when the CSF was nulled (13%). The effect however was larger in terms of reducing the noise variance leading to an average gray matter noise decrease from 18.80 to 11.18 (41%), while the signal intensity in gray matter was also decreased from 1237.37 to 848.69 (31%). Although the CSF signal itself is decreased in amplitude by 6.4 fold, the temporal fluctuations in CSF ROIs placed in the ventricles were reduced by only 2.2 fold (mean CSF temporal fluctuations before nulling was 38.12 and after 17.2). This suggests that the standard model which describes the physiological noise as proportional to the signal itself [2] does not hold for the case of the IR prepped acquisition, perhaps due to CSF in-flow. This suggests that a non-slice selective IR prep or a nulling method based on the long T2 of CSF might gain larger reductions in physiological noise.

N	Gray Matter tSNR resting	Gray Matter tSNR CSF-inverted	% increase
1	63.27±6.25	73.44±7.12	13%
2	56.22±5.28	62.09±3.05	9%
3	50.52±7.83	59.73±6.75	15%
4	70.09±5.28	77.39±4.29	9%
5	72.45±8.32	84.58±7.35	14%
6	72.84±7.06	82.24±8.31	11%
7	80.74±4.80	91.32±4.70	12%
8	71.54±5.29	80.05±6.00	11%
9	69.64±9.29	79.01±8.87	12%
10	57.48±5.02	73.21±9.07	21%
11	70.16±5.49	80.60±9.33	13%
Mean	**66.85±8.88**	**76.70±9.29**	**13%**

Table 1. Averaged values of gray matter tSNR measurements obtained from the CSF-inverted images and the resting state data across areas of cortical gray matter. The %increase is also given.

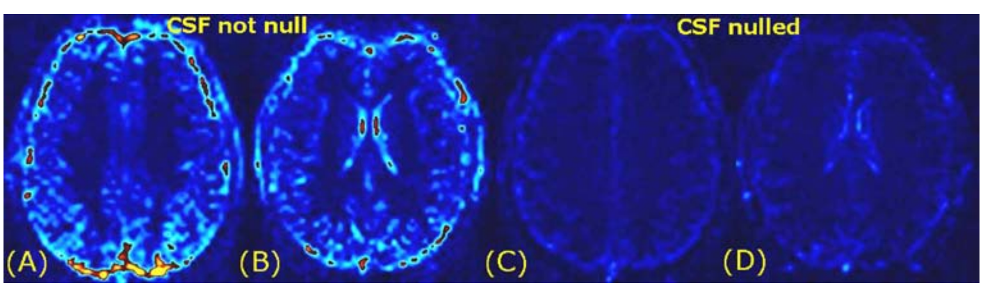

Figure 1. Spatial distribution of the physiological fluctuations across the fMRI time-series (SD maps) for the two acquisitions. (A) and (B) correspond to the resting state fMRI time series without inversion. (C) and (D) are the respective slices where the CSF was inverted. All maps are shown with a common scale.

Conclusion:

This study suggests that if physiological noise is to be mitigated during acquisition, the gray matter temporal SNR in the fMRI time-series will improve.

References: 1) Triantafyllou, et al, NeuroImage, 243-50, 2005 2) Krueger et al, MRM, 631-37, 2001 3) Bodurka, et al, ISMRM 2005, p1554.