Reducing Correlated Noise in fMRI Data

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Introduction

Due to its low sensitivity, BOLD fMRI generally requires extensive temporal averaging to detect brain activity changes in time-series data. Detection is compromised by thermal noise, instrumental instabilities, head motion, fluctuations in physiology and uncontrolled neuronal activity [1]. Often these sources coherently affect a large brain region, yielding extensive spatial patterns of temporally correlated noise. We introduce a new noise suppression method, model-free and simple to implement, which exploits this coherence: A noise estimate from a region outside the area targeted by the stimulation paradigm is used as a regressor in the analysis.

Materials and Methods

The method requires acquisition of a limited amount of (resting-state) reference data. The order of events in data processing is as follows:

1 Estimate the active region, R_{Act}, using conventional statistical analysis of the functional data.

2 Compute the average signal time-course in the reference data for the voxels within R_{Act} (referred to as $S_{RAct,Rest}$).

3 R_{Ref} is formed from voxels that were below 75% of the significance threshold in step *1* and that, in the reference dataset, correlate more than a preset threshold (here 0.5) with $S_{RAct,Rest}$.

4 The correlated noise regressor is formed by averaging the signal time-course in the functional data in R_{Ref}, which is then decorrelated from other regressors used in step *1*.

5 Finally, functional analysis similar to step *1* is performed using a design matrix that is expanded with this additional correlated noise regressor. (To avoid a bias, voxels in R_{Ref} are excluded from this step.)

BOLD fMRI experiments were performed on a 3.0 T GE Signa MRI scanner using a 16-channel detector. Six volunteers were scanned under an IRB-approved protocol (single-shot gradient-echo EPI; 44 ms TE; 1000 ms TR; 2.3×2.3×2.0 mm^3 nominal voxel size). Each subject was exposed to a 5 min, 30 s off/30 s on, visual block paradigm, which was followed by a 5-min rest period. A 7.5 Hz contrast-reversing radial checkerboard was shown during on-periods, a uniform 50% grey disk during off- and rest-periods. Volumes 16 though 315 were used as functional data. Part of the remainder of the data was used as reference for determining R_{Ref}.

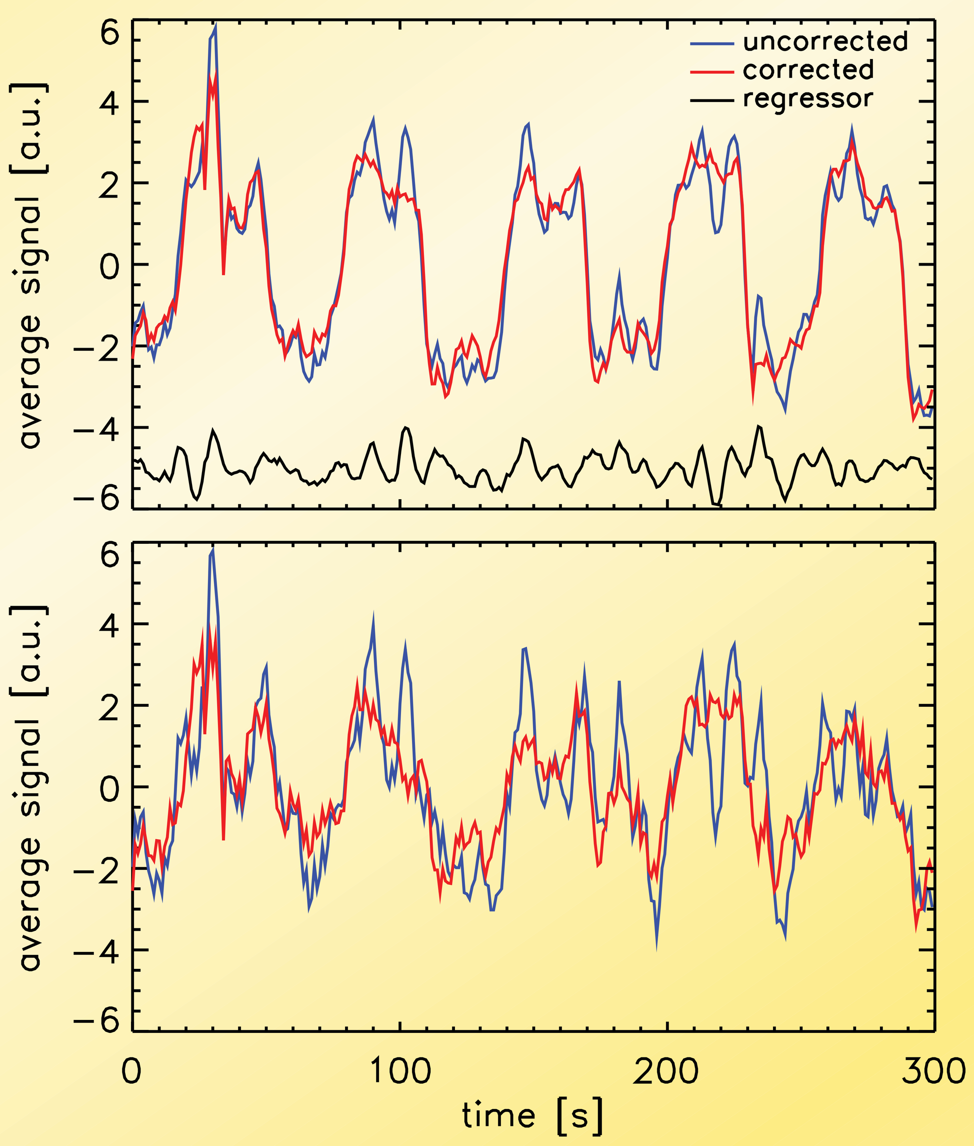

Figure 1: Average signal time course in the activated voxels of volunteer 2 for original data (blue) and data from which correlated noise was removed using the proposed method (red). The top panel shows the average for voxels that were significantly activated in the analysis without the correlated noise regressor, the bottom panel voxels that were only significantly activated when using the proposed method. The correction regressor used is shown in black in the top panel. (For figure clarity, an offset of -5 a.u. was used.)

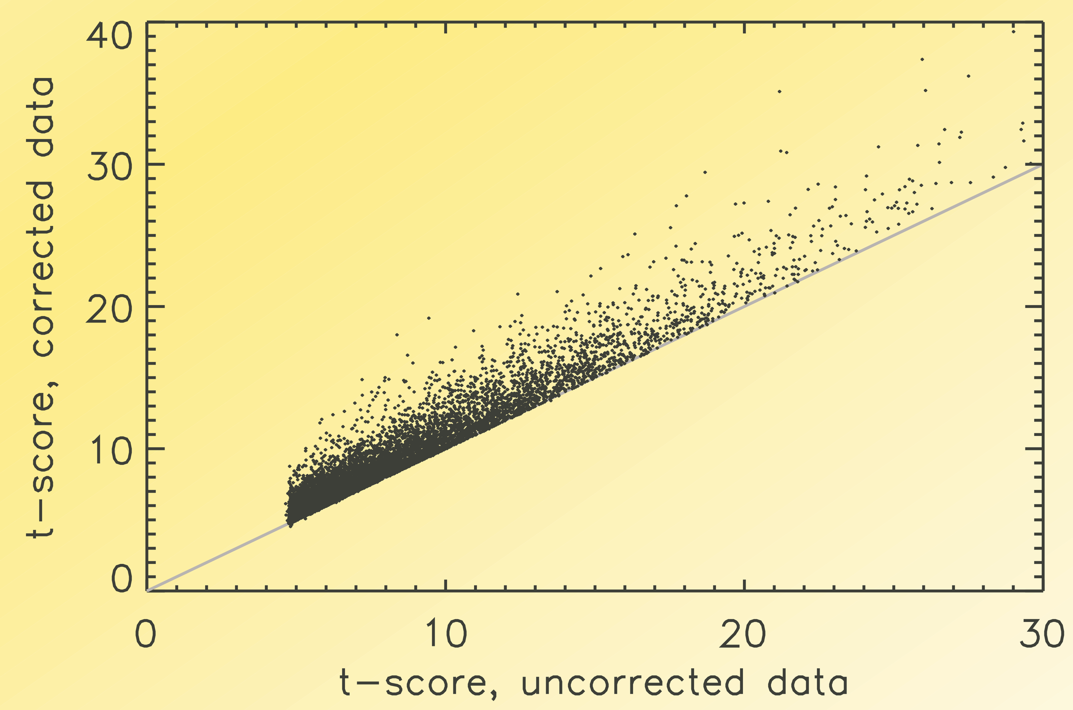

Figure 2: Scatter plot showing t-score improvement in activated voxels when the proposed method was applied compared to when the noise-estimate regressor was not taken into account (9057 voxels in 6 volunteers).

Results and Discussion

The proposed correction method significantly improved statistical performance of the fMRI experiment in virtually all voxels in all volunteers. Figure 1 shows the average signal time course in the activated area for one of the volunteers, before and after correction. Figure 2 shows a scatter plot of t-score obtained with correction as a function of t-score without correction for all voxels that were significantly activated when not accounting for correlated noise. Figure 3 shows an example of the regions involved for 4 slices for one of the volunteers. Table 1 shows that on average the t-score improves by 13.3±1.3 % and the number of activated voxels by 22.6±7.1 %. Fitted activation amplitude did not change significantly (-0.4±0.4 %), showing that t-score improvement was due to reduced SD. Data shown were derived from the analysis using 120 s of reference data. Results when using 30, 60, 180 or 270 s worth of reference data were not significantly different, nor was performance affected by the use of another correlation threshold to determine the reference mask (Table 1). In conclusion, this method allows for substantial increases of detection sensitivity at the cost of the loss of a single degree of freedom (accounted for in our functional analysis) and the need for the acquisition of a small amount of additional data (on the order of one or a few minutes per volunteer per session).

Reference

[1] MD Fox et al., Nat Neurosci 9, 2006, p 23

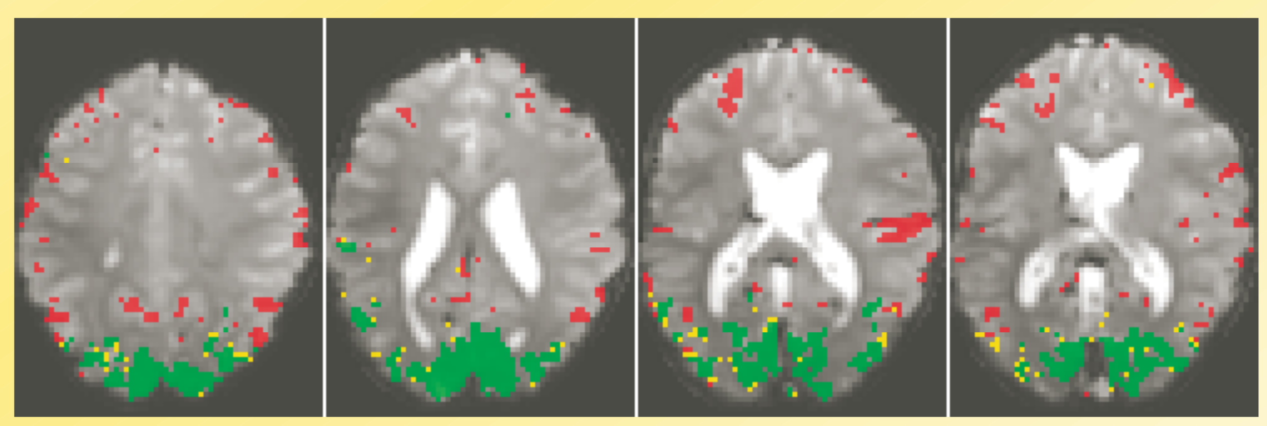

Figure 3: Masks used for analysis with correlation threshold 0.5 and 120 s worth of reference data, shown for 4 out of 10 slices for volunteer 2. The significantly activated area when not accounting for correlated noise is shown in green. Additional voxels activated when applying our method are shown in yellow. Reference mask voxels are shown in red.

Volunteer	t-score change [%]	amplitude change [%]	residue variance change [%]	number of active voxels change [%]	number of active voxels change	number of voxels in R_{Act}	number of voxels in R_{Ref}
1	16.6 (0.3)	-0.92 (0.02)	-8.7 (0.1)	13.9	262	1879	411
2	10.8 (0.3)	0.39 (0.01)	-4.8 (0.1)	10.9	210	1918	933
3	16.8 (1.3)	-0.19 (0.02)	-14.0 (1.1)	55.1	75	136	7892
4	13.4 (0.3)	-2.34 (0.07)	-8.0 (0.3)	27.5	278	1012	1206
5	13.6 (0.4)	-0.14 (0.01)	-6.5 (0.2)	19.3	299	1547	2055
6	8.9 (0.2)	0.69 (0.02)	-3.4 (0.1)	8.7	224	2565	150
Mean	13.3 (1.3)	-0.42 (0.4)	-7.6 (1.5)	22.6 (7.1)	225 (33)	1510 (344)	2108 (1188)
Mean (thres=0.4)	13.4 (1.7)	-0.43 (0.4)	-7.7 (1.7)	22.8 (7.2)	226 (32)	1513 (343)	3948 (1900)
Mean (thres=0.6)	11.9 (0.8)	-0.34 (0.4)	-6.7 (1.3)	21.4 (6.5)	216 (34)	1508 (345)	553 (245)

Table 1: Noise reduction performance, indicated by the observed changes when using the proposed method compared to (otherwise identical) analysis without the noise-estimate regressor. A voxel selection threshold for the reference region of 0.5 was used unless otherwise noted (lower two rows). Standard errors are between parentheses.

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