Sources of fMRI signal variance in the human brain at rest: a 7T study

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Purpose: To exploit the increased BOLD contrast available at 7T for fMRI studies, it is crucial to identify and separate the various noise sources. The aim of the present study was to determine the contribution of non-thermal noise to fMRI signal fluctuations in the visual cortex and in the gray matter at 7T during rest. The following noise sources were considered: 1) low frequency drifts due to scanner instability; 2) motion due to respiration and cardiac cycles; BOLD effects due to fluctuations in the rates of 3) respiration volume change and 4) cardiac pulsation; 5) thermal noise; 6) other sources, tentatively attributed to spontaneous neuronal activity.

Methods: Eight subjects (5m/3f, age 33±4) participated in the study (IRB approved protocol). GE-EPI BOLD fMRI was performed at 7T (GE Medical Systems) using 16 receive-only coil-elements (NOVA) and the following parameters: TE = 32ms; TR = 3s; 115 scans; F.A. = 75°; 36 slices; 1.25x1.25x2mm^3 voxels; slice spacing: 0.2mm; SENSE rate = 3. We also recorded the timing of physiological cycles (sampling rate = 250 Hz) by the use of a pulse-oximeter and the respiratory bellows provided with the MR scanner. We defined a region of interest in the visual cortex and one representing the whole gray matter by the use of a functional localizer and a global signal regression procedure, respectively. After standard image preprocessing, fMRI signals were converted to % signal change relative to their time average. Non-thermal noise sources 1)-4) were respectively modeled with: 1) three polynomial regressors; 2) eight RETROICOR regressors [1]; 3) two RVT regressors [2] shifted at lag +3s and +21s; 4) two Cardiac-rate regressors [3] shifted by lags of +3s and +15s. These lags were chosen using a lag optimization procedure (see Fig. 1). The % fMRI signal variance explained by source 1)-4) was computed as the R^2 value adjusted for the degrees of freedom (adjR^2). The % signal change (SC) from source 1)-4) was computed from the signal variance (σ^2) as follows: $\sqrt{(\sigma^2 \cdot \text{adj}R^2)}$. The SC due to thermal noise was estimated as the inverse of the image signal to noise ratio (SNR). SNR was calculated by dividing the signal in each voxel at a fixed time point by the square root of the noise covariance in the same voxel. The adjR^2 and SC assumed to be due to spontaneous resting state fMRI activity were determined from the residual signal variance after accounting for noise sources 1)-5). We computed adjR^2 and SC for signals both at the voxel level and averaged within ROIs.

Results: For each source, the explained variance and the signal change in the visual cortex and the total gray matter are shown in Fig. 2. The SNR in the visual cortex and in the gray matter (mean±s.e. across subjects, after averaging across voxels within ROIs) was equal to 70.7±4.2 and 64.9±4.2, respectively.

Conclusions: Low-frequency drifts are a major source of non-thermal signal fluctuation. We suggest the selection and use of four lagged noise regressors as an effective model to explain the variance related to the BOLD effects due to changes in the rate of respiration volume change and cardiac pulsation. Compared to the whole gray matter, the visual cortex has larger signal fluctuations due to both fluctuations in the rate of respiration volume change and spontaneous resting state activity (paired t-test, $p < 0.05$), demonstrating its high BOLD sensitivity to physiological changes and to neuronal activity. Our findings demonstrate that at 7T with a resolution of 3mm^3 spontaneous fMRI activity is still one of the major contributors to the total fMRI signal fluctuations.

References: [1] Glover et al., MRM 44:162-167, 2000. [2] Birn et al., Neuroimage 31:1536-1548, 2006. [3] Shmueli et al., Neuroimage 38:306-320, 2007.

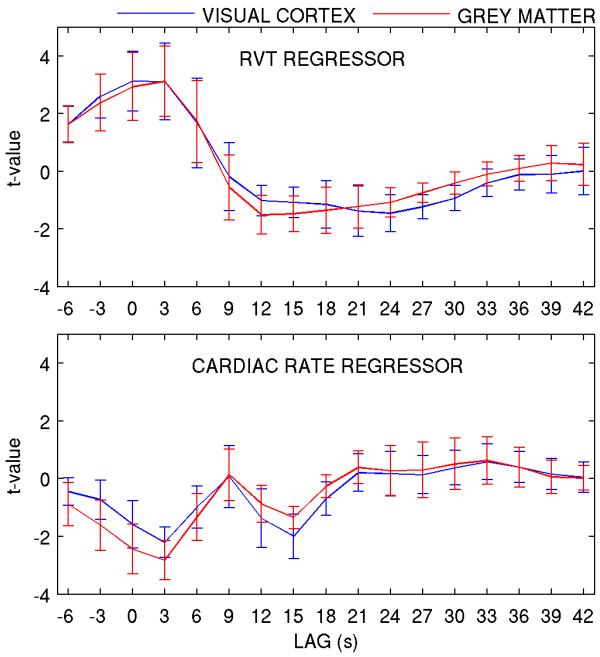

Fig. 1 T-value (mean ± s.e. across subjects) of the fit between ROI-averaged time-series and RVT and Cardiac-rate regressors shifted over a range of lag times. For RVT time lags = +3s, +21s correspond to the maximum and minimum t-values, respectively. The Cardiac-rate regressor shows two (negative) peaks at time lags = +3s and +15s.

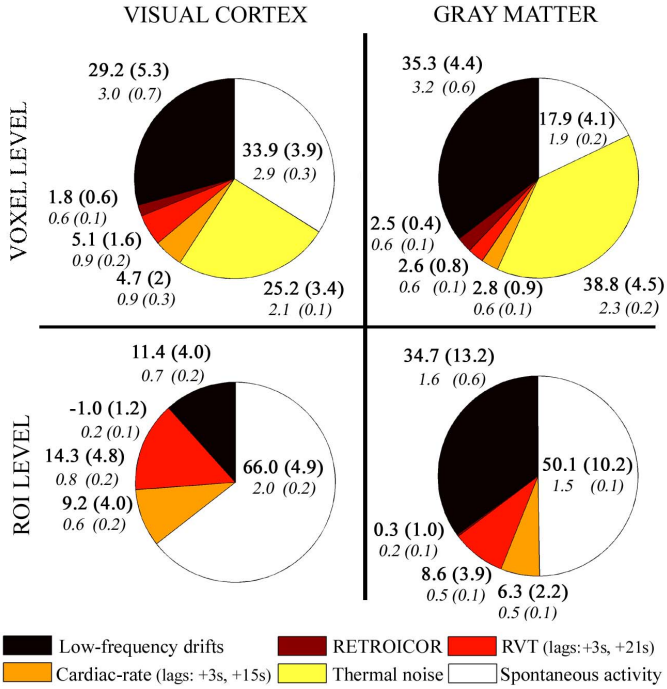

Fig. 2 Pie-charts showing the explained variance (adjR^2, %, upper **bold**) of fMRI data and fMRI signal change (SC, %, lower *italic*) relative to non-thermal noise sources 1)-4), thermal noise and spontaneous activity (average (s.e) values across subjects). The contribution of thermal noise at the ROI level was negligible.