The use of multiple physiologic parameter regression increases gray matter temporal signal to noise by up to 50%

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Introduction:

The temporal signal-to-noise ratio (TSNR) achievable in T2*-weighted MR imaging time series is limited by the presence of fluctuations that increase with image signal-to-noise (SNR) [1]. These "physiologic" fluctuations result in part from cardiac pulsation, respiratory movement, brain motion, changes in arterial CO2, and potentially, spontaneous neuronal-induced blood oxygenation (BOLD) changes. The achievable TSNR (TSNR limit has been found to be tissue specific, with the highest TSNR limit in white matter, and the lowest in CSF and blood vessels [1,2].
In a previous 3T fMRI study at low resolution (3.4mm x 3.4mm), correction for cardiac and respiration induced noise [3] resulted in approximately a 10% increase in the TSNR limit in gray matter [1]. Higher resolution (1.7mm x 1.7mm) studies of the TSNR limit suggest that this increase may be primarily mediated by a reduction of the noise in blood vessels and CSF [2]. Additional correction schemes have recently been proposed and implemented to reduce signal fluctuations unrelated to neuronally-induced BOLD changes. These include: 1) regressing out slow (~0.03Hz) respiration volume changes that lead to fluctuations in arterial CO2 [4,5] , 2) regressing out motion parameters [6], 3) regressing out global signal changes [6,7], and 4) regressing out signal changes from white matter [7]. The goal of the present study is to compare and evaluate the effectiveness of these corrections as a function of tissue type – white matter, gray matter, CSF, and blood vessels.

Methods:

A series of axial T2*-weighted echo-planar images were acquired on a 3T General Electric Excite3 MR scanner, with a receive-only eight element RF coil (Nova Medical Inc). (TR: 3s, TE: 30ms, FOV: 22cm, matrix: 128x128, 4mm slice thickness, 80 volumes per run.) Subjects rested with their eyes closed (n=4). Six runs at different flip angles (90, 70, 45, 30, 10, 0 degrees) were acquired in order to parametrically vary the image SNR. An additional EPI run with a long TE (55ms) was acquired to map the location of veins [8,9]. Segmentation of gray matter, white matter, and CSF was performed using T1 values estimated from the signal intensity at the first data point relative to the steady-state [2]. Image volumes were registered in time to correct for subject motion. Heart rate and respiration were recorded with a pulse oximeter and a pneumatic belt, respectively. Respiration volume changes were estimated by dividing the difference between the maximum and minimum belt positions by the time to the preceding breath

Image SNR was computed as ratio of the mean signal (over time) and standard deviation of noise background corrected for different statistics of the noise in imaging object as compared to the background [10]. Temporal SNR was computed by dividing the mean signal (averaged over time) for each voxel at each flip angle by the standard deviation of that same signal over time. Values of TSNR and SNR were averaged for each tissue type and fit to a model function [1], $TSNR = SNR / \sqrt{1+\lambda^2 SNR^2}$. Five corrections were applied in succession – 1) RETROICOR to reduce cardiac and respiration effects [3], followed by regressing out 2) respiration volume changes, 3) motion parameters, 4) the average signal over the whole brain, and 5) the average signal over white matter.

Results + Discussion:

Representative data from one subject is shown in Figure 1. With increasing SNR, the TSNR approaches a limit, which is highest for white matter, and lowest for CSF and vessels, in agreement with earlier studies. The difference in the temporal standard deviation resulting from adding each correction is shown in Figure 1f. Corrections for fluctuations at cardiac and respiration frequencies (RETROICOR) as well as regressing out respiration volume changes significantly reduced the temporal variation near blood vessels and CSF. Detrending the estimated motion parameters reduced variance at the edge of the image. TSNR was improved in all compartments. Larger effects were observed in regions with a high TSNR, since even a small decrease in variance results in a large TSNR improvement. Regressing out global and white matter signal changes had the most significant improvement in TSNR in white matter, and relatively little effect in other compartments.

Conclusions:

In addition to more conventional physiologic correction routines [3], regressing out estimated motion parameters and slower changes in respiration volume lead to TSNR improvements of up to 45% gray matter. The improvement using RETROICOR was, in agreement with previous studies, only about 15%. The remaining physiological (SNR-dependent) noise after elimination of these components is more likely to reflect BOLD changes resulting from resting state fluctuations in neuronal activity. The use of these additional regressors may be critical in accurate interpretation of studies involving assessment of baseline spontaneous fluctuations reflecting functional connectivity.

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