Temporal Autocorrelation of Noise for BOLD and IRON fMRI

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Introduction

IRON (Increased Relaxation for Optimized Neuroimaging) contrast has significant advantages over BOLD (Blood Oxygen Level Dependent) contrast for fMRI in animal models. IRON contrast has much better functional sensitivity than BOLD contrast, both in block designs[1] and in event-related (ER) designs using randomization of interstimulus intervals (ISI) and/or event types[2,3]. It has also been shown, to first approximation, that both BOLD and IRON responses are linear[4,5], and a General Linear Model (GLM)[1,5,6,7] formalism appears to accurately estimate the hemodynamic response and to successfully detect activation in most paradigms. This work examines the noise in fMRI experiments using BOLD and IRON contrasts; specifically, we observe temporal correlations within a first order autocorrelation model, or AR(1). Possible sources of autocorrelated noise are signal dependent physiological noise, imprecise hemodynamic impulse response functions, or motion correlated with stimulus presentation. As both methods of contrast are accurately described by linear model predictions over the range of stimuli employed, and correlated motion will contribute equally to both, we expect physiological noise to be a dominant factor explaining any observed differences in AR noise. In this case, the autocorrelated noise will be smaller for the IRON method, and the spatial distribution will differ between the methods, reflecting different underlying physiology.

Methods

Two monkeys were trained to perform a high acuity fixation task while full field black and white checkerboard stimuli were presented in the background. Rapidly presented stimulus paradigms, with fixed or random ISIs, were acquired for average ISIs of 4, 12 and 20 sec. Two experimental sessions were performed in a 3 Tesla Siemens Allegra scanner using a custom surface coil for the RF excitation and reception of signal. All functional imaging employed single-shot multislice EPI with an isotropic resolution of 1.5 mm. 25 slices were acquired with a TR of 1.5 sec and TE of 21 msec. BOLD and IRON data were acquired in different sessions. We employed a linear time-invariant model for the observed fMRI response, such that the signal is described using a GLM with impulse response estimators of the hemodynamic response, as determined in a previous work[1]. We modeled the correlation structure of the noise using a first order autoregressive model

$$\varepsilon_i = \rho\varepsilon_{i-1} + \chi_{i1},$$

where $\rho < 1$ and χ_{i1} represents white noise. With such a model, the autocorrelation decays exponentially as the lag l increases:

$$Cor(\varepsilon_i, \varepsilon_{i-l}) = \rho^{|l|}.$$

The constant ρ was calculated for each session as the average across all runs. The data was pre-whitened using the above AR(1) and the residual autocorrelation was again determined to evaluate the effectiveness of the model. Average maps of the AR coefficients were generated for BOLD and IRON methods.

Results

As observed in figure 1, an AR(1) model is enough to explain the correlations in the residuals. The average maps of the AR coefficients for BOLD and IRON in a single session are shown in figure 2. The average autocorrelation coefficients obtained for BOLD and IRON were approximately 0.21±0.01 and 0.12±0.01 respectively, and were not significantly different within activated areas with respect to the whole brain. The CNR for BOLD and IRON contrast was not significantly altered by accounting for correlation structure of noise. With BOLD contrast, the brain areas showing higher AR coefficients appeared to be areas of high blood volume, such as sulci. The same was not observed with IRON contrast.

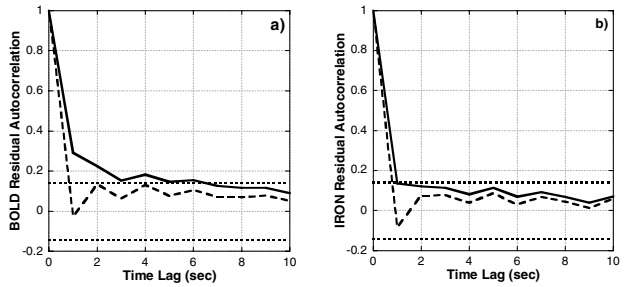

Figure 1 Residual autocorrelation of typical a) BOLD and b) IRON runs, before (solid line) and after (dashed line) applying an AR(1) model to the data. Horizontal dotted lines are $\pm 2/\sqrt{N}$, Bartlett's approximate 95% confidence interval.

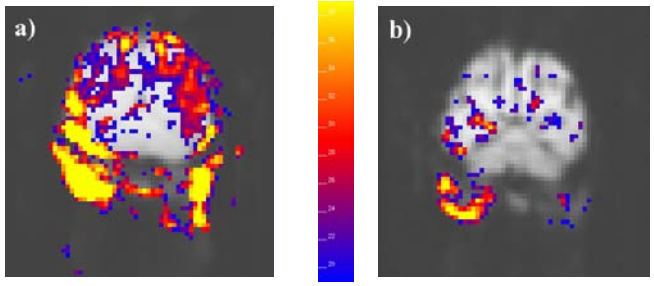

Figure 2 Average maps of AR(1) coefficients for a) BOLD and b) IRON in a typical session. The AR coefficient values were multiplied by a factor of 100. For BOLD contrast the AR coefficients appear to be especially elevated in areas of high blood volume. For both methods, the regions below the brain showing elevated coefficients correspond to the shoulders.

Discussion and Future Work

The BOLD noise correlation is on average twice the IRON noise correlation, which is same ratio of SNR between the two techniques (injection of iron decreases SNR, and increases signal changes). Therefore, the AR noise seems to fall in the category of physiological noise that scales with signal, consistent with temporal SNR calculations done by numerous groups[8,9]. The inclusion of an AR(1) noise model in the GLM analysis does not significantly affect CNR, therefore the AR noise scaling has relatively little effect on differences between BOLD and IRON sensitivities. The BOLD noise correlation within the brain is stronger in areas of high blood volume, such as sulci, consistent with known BOLD underlying physiology. Nevertheless, a more thorough investigation of the spatial distribution of the autocorrelation coefficients is necessary.

References [1] Leite et al, NeuroImage 2002; [2] Leite et al, Proc ISMRM 2004; [3] Leite and Mandeville, NeuroImage 2005; [4] Lu et al, NeuroImage 2005; [5] Boynton et al, J Neurosci 1996; [6] Friston et al, Hum Brain Mapp 1995; [7] Dale and Buckner, Hum Brain Mapp 1997; [8] Kruger and Glover, MRM 2001; [9] Triantafyllou et al, NeuroImage 2005.