Removal of temporal correlation in fMRI time-series using RETROICOR: - a simulation study

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Introduction: When assigning significance to fMRI activations a common problem is that the residuals are correlated and non-white. Part of this correlation is suspected to be due to aliased cardiac and respiratory oscillations. If the precision of the phase of an externally recorded physiological measure (e.g. EEG) is sufficiently high, these aliased oscillations could in principle be removed using physiological noise correction e.g. with the RETROICOR method proposed by Glover et al. 2000. If able to successfully remove these serial correlations in the errors, RETROICOR could potentially substitute autoregressive modelling which is difficult and time consuming. The purpose of the simulation presented here is to get a rough estimate of the preciesion needed in the physiological estimates.

Methods: Twelve datasets each consisting of 381 volumes of four slices (matrix size 64x64) were generated. First all voxels in the 4D volume were given a constant value of 100 plus normal-distributed white noise of a standard deviation specific to the dataset (The used values were [0.01 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1]). In selected voxels, oscillatory noise of f_i=1Hz, 2Hz and 3Hz was sampled with TR=2.37s, and added to the time course as described in Figure 1. Each dataset was subsequently analysed in SPM2 using a simple model: $y(t) = \beta_1\mu + \varepsilon(t)$, and 28 RETROICOR models: $y(t) = \beta_{2i-1}\sin(\phi_i(t) + (2\pi\Delta_j(t) f_i)) + \beta_{2i-1}\cos(\phi_i(t) + (2\pi\Delta_j(t) f_i)) + \beta_n\mu + \varepsilon(t)$, where ϕ_i is the phase of the i'th underlying oscillation (this would correspond to the phase of e.g. the cardiac cycle). $\Delta_j(t)$ are j=28 different levels of white normal-distributed jitter added to the phase of the reference time course. The standard deviation for the 28 levels of jitter added to the phase were: [0 1 2 3 4 5 6 7 8 9 10 15 20 30 35 40 50 60 70 80 90 100 120 140 160 180 200] ms. After the analysis, Statistical Parametric Mapping diagnosis (Luo & et al. 2003) was used to test the whiteness ("Dep" for arbitrary stationary dependence and "Corr" for AR(1)-type autocorrelation) and normality "Norm" of the residuals $\varepsilon(t)$, from the different models.

Results: In Figure 2 we show the output from SPMd of the dataset with a standard deviation of the white noise of 0.5. Three things are observed from the figure. The simple model does not give white errors (SPMd_PDep and SPMd_Pcorr) in the voxels where oscillations were added. At jitter-values lower than 30ms the method seems capable of removing the aliased noise of even the 3Hz oscillation, whilst at higher jitter values only the slower oscillation can be removed. At this noise level the normality test (SPMd_PNorm), has problems in identifying the aliased 1 Hz oscillation as non-normal. Figure 3 show corresponding results across the different levels of the added white noise. The method seems efficient in perfectly removing correlations in the noise and makes it more normal if the phase of the estimated regressor is known with a standard deviation around 30 ms.

Discussion: The results show that the necessary precision of the phase measurement provided by external recording (ECG, pulseoximetry, respiratory belt) increases with the frequency of the oscillation in question. Correspondingly a longer TR will also require higher precision. Our simulation show that correlations due to aliased physiological noise can give rise to non-white non-normal noise, and that these can be modelled satisfactory using RETROICOR, or similar methods. The results indicate that 1Hz oscillations sampled at 1/(2.37s) should be almost completely removable with the quality of the time courses provided by scanner vendors (e.g. on newer Siemens systems ECG is sampled at 200Hz and pulseoximeter 50Hz). For higher frequencies, or longer TR's, the results are less optimistic.

References:[1]Glover et al. 2000, MRM, **44**, 162–7. [2] Luo et al. 2003, NeuroImage, **19**, 1014–32.

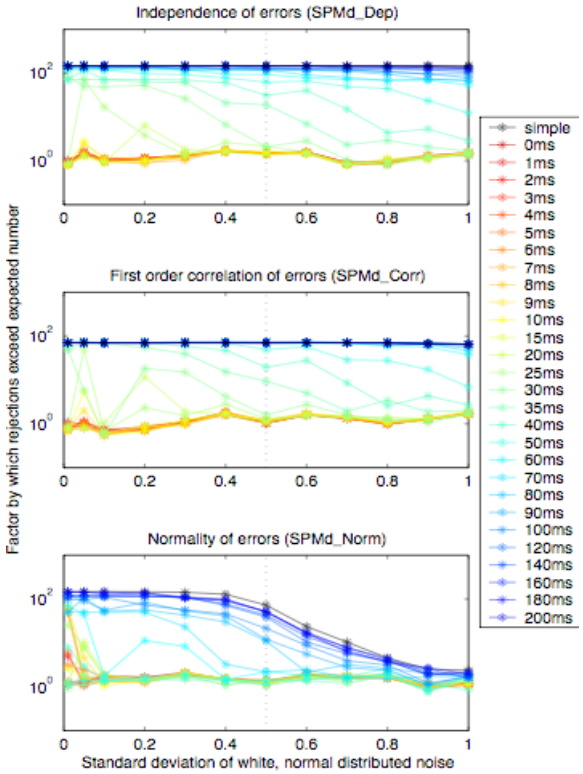

Figure 3 (Above): The figure shows for the three different tests, as a function of increasing standard deviation of the white noise, the factor by which rejections exceed the expected number. The different curves correspond to a simple analysis and several analyses using an external reference time course to whiten the periodic behaviour. Different colours indicate the standard deviation of the jitter introduced to the phase of the reference time course. The vertical dotted black line at 0.5 indicates the noise-level of the dataset used in Figure 2.

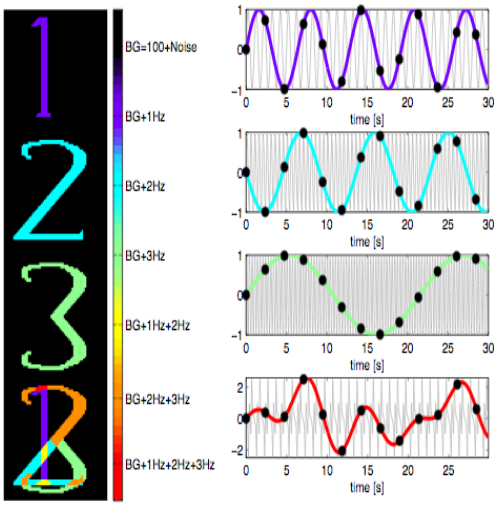

Figure 1 (Left): Construction of simulated data. The figure show how the dataset used for the simulation was constructed. The different colors correspond to aliased harmonic oscillations.

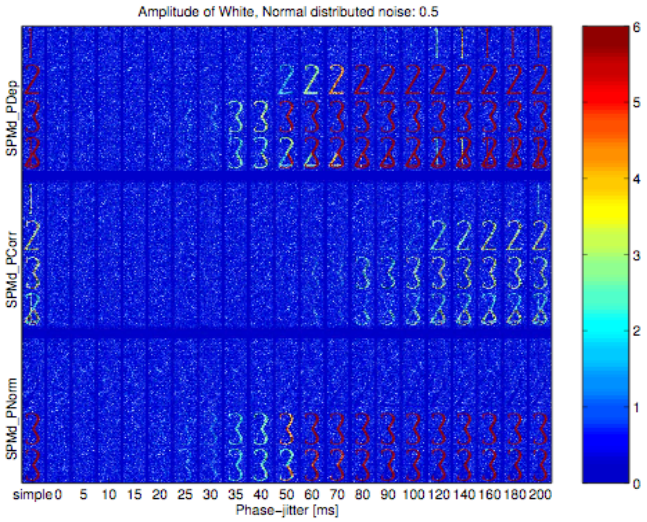

Figure 2 (Right): The figure shows the output of a SPM-diagnosis (log(p) values) from the simple analysis and from several analyses using an external reference time course to whiten the periodic behaviour. In the horizontal direction, increasing jitter has been introduced to the phase of the reference time course.