Assessment and Correction of Subject Motion in Physiological Noise Regression

T. B. Jones[1], P. A. Bandettini[1], and R. M. Birn[1]
[1]Laboratory of Brain and Cognition, National Institute of Mental Health, Bethesda, MD, United States

Introduction:

Physiological fluctuations are the dominant source of noise in Blood Oxygenation Level Dependent (BOLD) fMRI [1]. Current methods of physiological correction (e.g. RETROICOR) reduce noise by modeling fluctuations with a low order Fourier fit based on the phase of cardiac and respiratory cycles during each image acquisition [2]. These methods generally do not consider motion effects, which have the potential to significantly reduce the efficacy of physiological noise correction. The purpose of the present study is to assess the impact of motion on these physiological correction techniques and to account for this impact.

Modeling fluctuations prior to image registration is difficult because the sources of these fluctuation can move into or out of voxels. Image registration spatially realigns sources of fluctuation, but the newly resampled voxels have effectively been acquired at a mixture of times. This can introduce errors of several seconds (depending on the TR) to the phase estimate within the physiological correction routine, much larger than the cardiac cycle. Traditional slice time correction (using interpolation) prior to registration is not advised, since the cardiac fluctuations are much faster than the TR. Similarly, allowing for a time shift of the fluctuations does not completely account for these timing errors since the contribution of times to each voxel changes with motion [3]. A possible solution is to modify physiological correction to account for the different times of acquisition of each voxel after registration.

Methods:

The effect of motion on physiological noise correction was first studied by simulation. A known sinusoidal signal with varying frequency (1.23 +/- 0.16 Hz) mimicking a cardiac response was added to a dataset. This dataset was rotated and translated to simulate motion and resliced to simulate variable slice timing. RETROICOR was applied either before or after image registration. The results were compared to a modified version of RETROICOR that took the effects of motion into account (Eq. 1). This modified version determined the proportion that each pre-registered slice

$$y_c(x,t) = \sum_{m=1}^{M} \sum_{nz=0}^{NZ} w_{nz}(x,t)[a_{nz}^c(x)\cos(m\phi_c(t)) + b_{nz}^c(x)\sin(m\phi_c(t))] \qquad (1)$$

contributed to every voxel and time point after registration, $w_{nz}(x,t)$. Fluctuations were then modeled as a linear combination of sines and cosines (M = 2) with the phase relative to the heart beat, $\phi_c(t)$, measured for each contributing slice's acquisition time. $y_c(x,t)$ is the cardiac-induced signal fluctuation, NZ is the number of slices, and a and b are fit coefficients determined in the regression analysis.

The effect of motion on RETROICOR was evaluated for one healthy volunteer who moved significantly during the imaging runs (0.34^o roll, 1.70^o pitch, 0.54^o yaw, 2.39mm dS, 0.44mm dL and 0.51mm dP). The subject performed three resting runs, each corresponding to the three different anatomical planes of slice acquisition (TR/TE=3000ms/30ms, FOV=24cm, voxel size 3.8 x 3.8 x 3.8 mm^3, 165 time points). Physiology was recorded with a pneumatic belt positioned around the chest and an infrared pulse oximeter on the index finger. The normalized standard deviation reduction accomplished by RETROICOR was used as a measure of its efficacy. In addition, the timing errors introduced by the motion were computed for each voxel.

Results and Discussion:

Figure 1 depicts the effect of motion on the simulated cardiac fluctuations. The simulation also shows the efficacy of RETROICOR in eliminating the sinusoidal signal after motion and image registration, the modified method showing marked improvement over the traditional method (Fig. 1). The smallest degree of timing errors occurred in the sagittal plane (Fig. 2). Accordingly, sagittal plane acquisition accomplished the largest noise reduction by RETROICOR for the individual scanned in all three anatomical planes (Fig. 3). These results agree with the limited amount of through-plane motion in the sagittal plane. Increased through-plane motion in the axial and coronal planes reduced the performance of RETROICOR (Fig. 3).

Conclusions:

These simulations, supported by the subject data, provide evidence that motion can have a considerable impact on the efficacy of physiological correction. Furthermore, the effects can be greatly reduced by updating RETROICOR, per Eq. 1, to account for the timing differences introduced by image registration. In addition, a voxel by voxel regression analysis could more accurately model the hemodynamic response by applying a method similar to that outlined in Eq. 1 to account for the interaction between motion and varying slice time acquisition. It is also worth noting that most of the motion was in the sagittal plane, a common occurrence in fMRI since it is difficult to restrain "head-nodding" movement; therefore, it is optimal to acquire sagittal slices to minimize these through-plane effects.

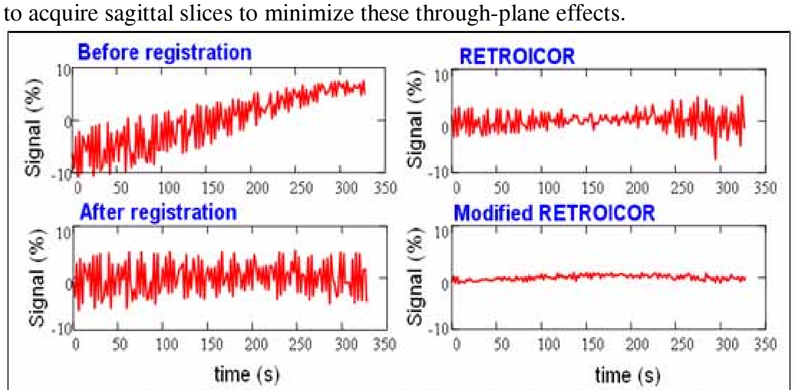

Figure 1: RETROICOR Performance with Simulated Cardiac Fluctuations

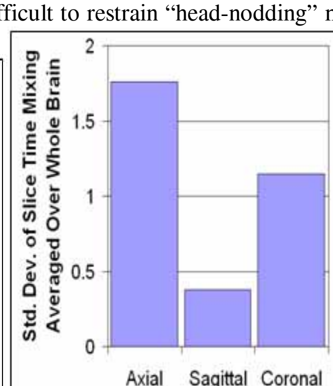

Figure 2: Amount of Slice Time Mixing for the Test Subject

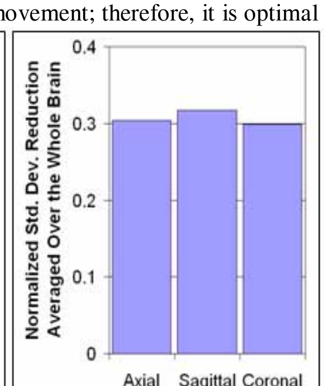

Figure 3: RETROICOR Efficacy for the Test Subject

References: 1. G. Krueger et al, MRM 46, 2001. 2. G.H. Glover et al., *MRM.* 44, 2000. 3. T.E. Lund et al., NeuroImage, 2005.