Respiratory noise Correction using linear Phase regression (RCP)

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Introduction: In fMRI experiments, the BOLD signals may be contaminated by respiratory movements. Several methods, such as RETROKCOR[1] and RETROICOR[2] have been proposed to remove the respiratory noise. These methos, which require the direct acquisition of respiratory signals, have been demonstrated effective. In this work, we proposed a new technique that does not need the acquisition of respiration signals. The respiratory noise can be estimated and removed from BOLD signal using a linear regression of the fMRI phases signals from multiple slices.

Theory: Respiratory movement causes a global field change in the brain. In previous works, it has been shown that this field change can induce the phase variation of the image data [3]. Fig. 1 shows an example. It can be seen that the respiration signal and the phase time series are highly correlated. Due to this correlation, it is possible to estimate the field change from the phase signal directly and remove it from the fMRI data. As shown in Eq. 1, an fMRI signal is composed of true fMRI signal *d(t)*, respiratory noise $n_r(t)$, and other additive noise *a(t)*. Our hypothesis is that the respiratory noise is linearly related to the phase time series, up to a shift in time. Since the phase time series from multi-slices are off by a temporal shift, the respiratory noise can be approximated as a linear regression of the phase time series of multiple slices P_i (Eq. 2). In Eq. 2, N should be greater than 1 and big enough to avoid Nyquist aliasing effect. By defining the correlation function of two arbitrary real time signals x(t) and y(t) as in Eq. 3, we have: $R(p,d) = R(p,a) = 0$, and $R(p,m) = R(p,n) \neq 0$. The coefficients for the linear regression model can be resolved from Eq. 4.

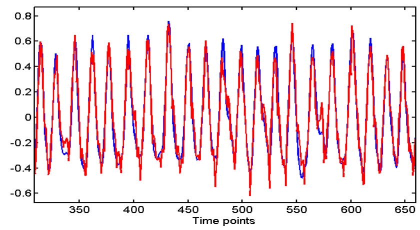

Fig. 1. Time series of respiration (blue) and phase (red). Correlation coefficient=0.95.

Equations

$$m(t) = d(t) + n_r(t) + a(t) \quad (1)$$

$$n_r(t) = \sum_{i=1}^{N} \alpha_i P_i \quad (2)$$

$$R(x, y) = \int x(t) y(t) dt \quad (3)$$

$$R(m, P_j) = \sum_{i=1}^{N} \alpha_i R(P_i, P_j) \quad (4)$$

Methods: Three subjects were scanned on a Siemens 3T Trio scanner using an 8-channel head coil (Siemens Medical Solutions, Erlangen, Germany). Each subject was scanned twice using the same EPI sequence with different TRs of 250 ms and 2000 ms. The subjects were at rest during the scan with eyes closed. The same four oblique slices of 4 mm thickness were acquired. Respiratory movement was recorded using a pneumatic belt. Phase information was calculated from the raw data. A mean phase time series was obtained from those pixels with standard deviation less than 0.2. Quadratic detrending was applied to the fMRI data and phase time series to remove signal drift. Finally, the fMRI data time series were corrected using our proposed approach (denoted as RCP) and RETROICOR. N = 2 for correction at TR of 250 ms; N = 4 for correction at TR of 2000 ms.

Results: Fig.2 shows two examples of the correction results using RETROICOR and RCP for TR 250 ms. The figures give the spectra of the fMRI time series and the respiration noise peaks can be seen near 0.2 Hz. Both RETROICOR and RCP are very effective in removing the respiration peak. Table 1 summarizes the comparison of temporal noise in the fMRI data time series from the voxels in the region of interest. In all cases, the performance of RCP is slightly better than RETROICOR. Fig. 3 shows the removed respiratory noise using the two methods for TR 2000 ms. The patterns are very similar to each other except that RCP picks slightly more noise.

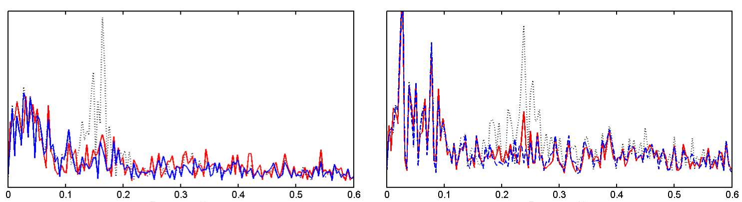

Fig. 2. Spectra of fMRI data time series within a region of interest. Doted lines: uncorrected; blue lines: RETROICOR; red lines: RCP.

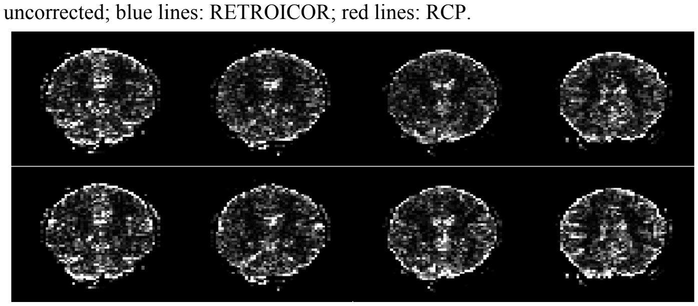

Fig. 3. Estimated respiratory noise by calculating difference between uncorrected and corrected. Top row: RETROICOR; bottom row: RCP.

Table 1. Temporal noise. U: uncorrected; I: RETROICOR; P: RCP.

	Subj1	*Subj2*	*Subj3*
		TR = 250 ms	
U	1.99	10.77	1.96
I	1.73	9.82	1.90
P	1.73	8.65	1.86
		TR = 2000 ms	
U	1.11	6.05	1.29
I	1.05	5.62	1.26
P	.997	4.96	1.23

Discussion: We have demonstrated that RCP is very efficient in the correction of respiration noise. It is a simple and fast technique. For multi-slice fMRI, there is no need to use all the phase time series of all slices. Four slices are good enough for the TR of 2 seconds in our experiments. An advantage of RCP is that this method does not need any extra setup for respiratory signal acquisition and therefore offers more comfort to the human subject in fMRI data collection.

References

1. Hu X et al., MRM 37:877-884 (1997). 2. Glover G et al., MRM 44:162-167 (2000). 3. Frank LR et al., MRM 5:635-644 (2001).