Respiratory Noise Correction Using Phase Information

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Introduction: fMRI time series can be significantly contaminated due to respiratory movements. Several methods, such as RETROKCOR[1] and RETROICOR[2] have been proposed to remove the respiratory effects. These methods usually require simultaneous acquisition of physiological signal during fMRI experiments. Because the equipments needed for signal acquisition can increase the discomfort of human subjects, the reliability of fMRI data may be reduced. Furthermore, these methods are efficient only when the respiration is quasi-periodic, which is not always true. In this study, a new method, respiratory noise correction using phase information (RCP), was developed to reduce the respiratory signals in fMRI data. This method takes advantages of the respiration information in the phase signal of complex fMRI data and does not need extra data acquisition. It was demonstrated that the respiratory noise can be removed efficiently using this method.

Theory: The reason why fMRI data can be contaminated by respiration is because respiratory movement causes a global field change in the brain. This field change can induce the phase variation of the image data. Fig. 1 shows an example. It can be seen that the respiration and the phase time series are highly correlated to each other. Due to this correlation, it is possible to estimate the field change from the phase signal directly and remove it from the fMRI data. This scheme, referred to as RCP in this work, is illustrated by Fig. 2. The solution to the Wiener filter in Fig. 2 can be resolved from Wiener-Hopf equations[3]:

$$\mathbf{R}_{\varphi}\mathbf{w} = \mathbf{r}_{s\varphi} \qquad (1),$$

where $\mathbf{R}_{\varphi}$ is the self-correlation of phase time series, $\mathbf{w}$ is the vector of Wiener filter coefficients, and $\mathbf{r}_{\varphi}$ is the cross-correlation of fMRI time series and phase time series.

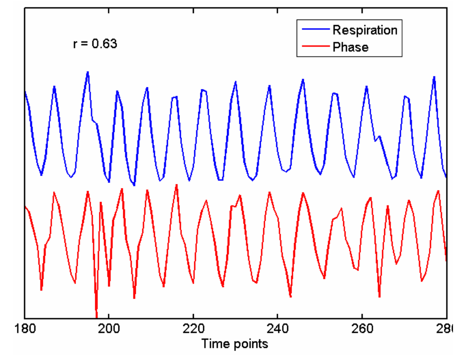

Fig. 1. Time series of respiration (top) and phase (bottom). Correlation coefficient=0.63.

Methods: Five subjects were scanned on a Siemens 3T Trio scanner using an 8-channel head coil. For each subject, eight oblique slices of 4 mm thickness were acquired using an EPI sequence (TR/TE = 500/30 ms). Visual stimuli were presented using a flashing checkerboard. Simultaneously respiratory data were recorded using a pneumatic belt at the sampling rate of 50 Hz. 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 time series to remove signal drift. A high-pass filter with a cutoff frequency of 0.1 Hz was applied to the mean phase time series. Finally, the fMRI data time series were corrected using RCP without the use of acquired respiratory signal. The corrected results were compared to those using RETROICOR with the use of acquired respiratory signal.

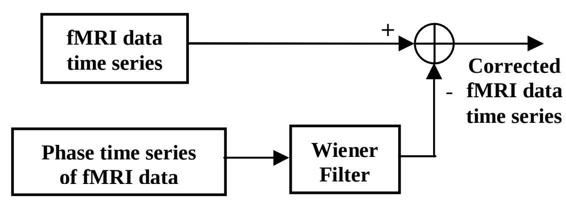

Fig. 2. Removal of respiration noise using Wiener filter

Results: Fig. 3 shows two examples of the correction results using RETROICOR and RCP. The figures give the spectra of the fMRI time series and it can be seen that the respiration noise peaks near 0.3 Hz. In the first example, the respiration peak is relatively narrow and can be easily removed by either method. In the second example, the respiration peak is relatively broad. Using RETROICOR, there still exists some residue noise after correction. Using RCP, the respiration peak is completely removed. Table 1 and 2 summarize the statistical comparison of the two methods for all 5 subjects. In Table 1, the ratio of respiratory signal power (the components near the respiration frequency ±0.05 Hz) to the total power is used to evaluate the two methods. It can be seen that RCP gives lower numbers, indicating better removal of respiration signals. Table 2 shows the temporal noise in the fMRI data time series from the voxels in the region of interest. In all cases, RCP generates lower noise than RETROICOR.

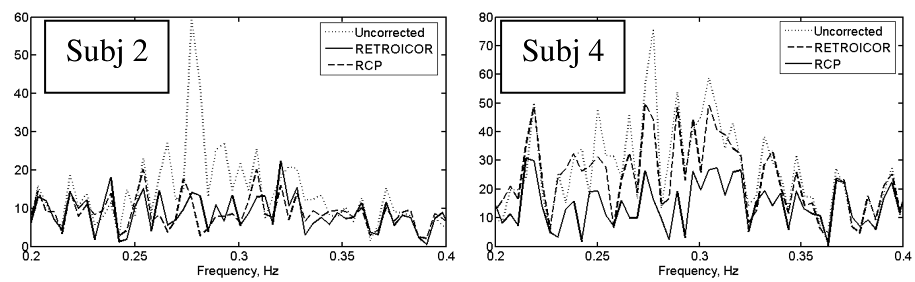

Fig. 3. Spectra of fMRI data time series within the region of interest. Doted line: uncorrected; Dashed line: corrected with RETROICOR; Solid line: corrected with RCP.

Table 1. Ratio of respiratory signal power to total power in percentage. U: uncorrected; I: RETROICOR; P: RCP.

	Subj1	Subj2	Subj3	Subj4	Subj5
U	0.58	0.70	0.74	0.73	1.39
I	0.45	0.40	0.49	0.63	0.89
P	0.37	0.41	0.43	0.36	0.60

Table 2. Temporal noise. U: uncorrected; I: RETROICOR; P: RCP.

	Subj1	Subj2	Subj3	Subj4	Subj5
U	0.738	0.616	1.155	0.963	1.908
I	0.697	0.548	1.018	0.918	1.421
P	0.688	0.546	0.977	0.807	1.067

Discussion: RCP is more efficient in the correction of respiration noise than other methods because it directly measures the local magnetic field change induced by respiration in fMRI data by using the phase signal. In the cases where the assumption that respiration is quasi-periodic does not hold, RCP can perform better. Another desirable feature of RCP is that this method does not need any extra setup for acquiring respiratory signal and therefore offers more comfort to the human subject in fMRI data collection.

Reference

1. Hu X et al., MRM 37:877-884 (1997). 2. Glover G et al., MRM 44:162-167 (2000). 3. Hayes M., John Wiley & Sons, Inc.