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Identification of Spatio-Temporal Oscillatory Signal Structure in Cerebral Hemodynamics Using DRIFTER

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INTRODUCTION

As the signal-to-noise-ratio of fMRI increases, enabling better spatial and temporal resolution, accurate treatment of physiological noise becomes increasingly important. Earlier work has revealed temporally and spatially structured cardiac and respiration -related physiological noises [1-3], and elimination of unwanted physiological noises from the fMRI data in optimal manner requires accurate modeling of the noise characteristics [4]. Furthermore, as the connectivity of the brain is often analyzed using correlations of low-frequency signals in brain, the elimination of the highly correlated physiological signals is crucial [7-9]. Recently, we introduced a Bayesian model based approach (DRIFTER) for separation of the physiological noises from other signal components [5,6]. The DRIFTER method is based on accurate modeling of the temporal structure of the signals using stochastic resonator models in combination with the interacting multiple model (IMM) method, Kalman filters (KF) and smoothers for implementation of the Bayesian estimation. In this work we analyze the spatio-temporal characteristics of the physiological signal components estimated by DRIFTER for the purpose of developing more accurate spatio-temporal noise models. In addition to analyzing the cardiac and respiration signals, we also study the spatio-temporal characteristics of a physiological 0.1 Hz oscillation (cf. [10]), which most likely has a vascular origin.

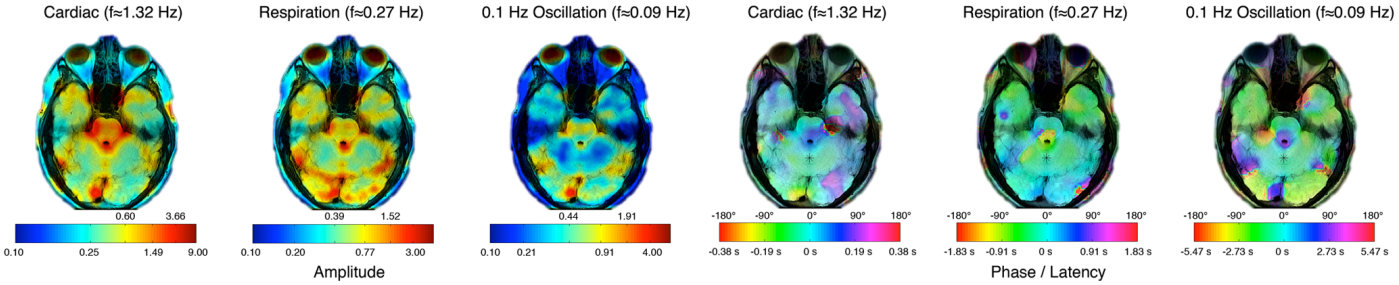
METHODS

We used a four-run set of fMRI data and anatomical images for one volunteer obtained with a 3.0 T scanner (Signa HDxt; General Electric) using a 16-channel (MR Instruments, Inc.) receive-only head coil. The sequence parameters were TR: 100 ms; TE: 20 ms; FA: 60 degrees; FOV: 20 cm; matrix size: 64x64; and voxel size 5 mm isotropic. Spatial coverage was limited to two slices. The stimuli consisted of 50 achromatic photographs of familiar objects presented in the center of the visual field of the volunteer. The stimulus condition was contrasted with fixation alone, and the four runs, each roughly 120 s in length, comprised of similar blocks (~15 s of stimulus-on and ~7 s of stimulus-off). The cardiac and respiration reference signals were acquired time-locked to the fMRI data using the scanner integrated peripheral pulse measure and respiratory belt. The sampling frequency of the physiological signals was 1 kHz.

We used three separate harmonic resonators in the DRIFTER algorithm. The first two were for cardiac and respiration, and their frequencies were estimated from the external cardiac and respiration signals. The frequency of the roughly 0.1 Hz oscillatory signal was estimated using the spatially averaged fMRI data as an artificial reference signal. The cardiac, respiration and 0.1 Hz oscillation signals were then separated using the Kalman filter and smoother according to the DRIFTER algorithm. The lowest frequency components of the oscillators were then converted into analytic signals and a spatial Gaussian smoothing filter was applied. The phase differences of the analytic signals at each voxel were then studied in terms of complex polar coordinates subject to a reference voxel and converted into time delays using the average frequency.

RESULTS

The estimated amplitudes of the cardiac, respiration and 0.1 Hz oscillation signals are shown in Figure 1 below (three first panels on the left) and the time delay maps are shown in Figure 2 (three panels on the right). The amplitude of the cardiac signal is strong in the middle near the circle of Willis as well as at the back near the posterior cerebral artery. The respiration signal also seems to have spatial structure in the amplitudes, which resembles that of cardiac, but is slightly more uniform. The strongest areas of the 0.1 Hz signal are quite similar to those of the cardiac signal. The phase of the cardiac signal in high-amplitude areas on the primary visual cortex V1 seem to have roughly 90-degree phase shift relative to other parts of V1 in the ipsi- and contralateral hemispheres. Some areas in the occipital lobe have 180-degree cardiac phase shift between the hemispheres. The 0.1 Hz signal on the high-amplitude area of V1 has a nearly 180-degree phase shift to other parts of V1, but the other parts on the visual cortex have quite the same phase.



DISCUSSION

The results indicate that the amplitudes of the oscillatory physiological noise signals have a non-uniform spatial amplitude and phase distribution. The amplitude distribution of the cardiac signal resembles the results of [2] and the amplitude distribution of the respiration signal was observed to have a clear spatial structure as well. The 0.1 Hz oscillatory signal was observed to have a similar amplitude distribution as cardiac, which suggests a vascular origin (cf. [3,10]) such as Traube-Hering-Meyer waves. There are clear phase differences between different brain areas in all of the signals. The computed amplitude and phase maps could be used as prior models for elimination of the physiological noises, but they may also provide valuable information on the brain functionality itself. As the phase differences of 0, 90, and 180 degrees imply correlation coefficients 1, 0, and -1, respectively, it is very important to properly eliminate the physiological signals before correlation based connectivity analysis, because otherwise the physiological signals are very likely to produce spurious correlations between brain areas. A near 180-phase shift in a signal (as in the 0.1 Hz signal) also means that if the signal is spatially averaged, the signal becomes attenuated or may even disappear completely.

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