# Cardio-respiratory effects on the phase in EPI

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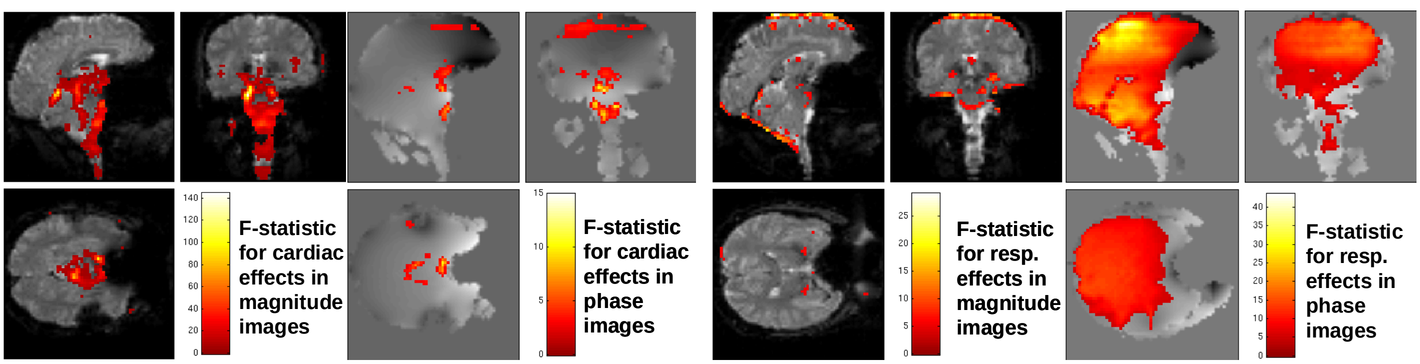
**Introduction**: Functional magnetic resonance (fMRI) imaging studies commonly use echo-planar imaging (EPI) to collect a times series of rapidly acquired images. This technique is favourably sensitive to changes in blood oxygenation associated with neuronal activity (1). Unfavourably this technique is also sensitive to physiological noise sources including cardio-respiratory effects and head motion. Here our attention is focussed on signal modulations brought about by respiration effects and cardiac pulsatility. Image-based methods have been proposed for the assessment and correction of cardio-respiratory effects. These methods fit low-order Fourier series to the image data taking into account the image acquisition time relative to the phase of the cardiac and respiratory cycles monitored using pulse-oximeter and respiratory belt (2-4). Furthermore, variations in respiration depth from breath to breath typically occur at frequencies lower than that of the respiratory phase and a method has been presented to model and spatio-temporally characterize these respiratory-variation-related fluctuations in fMRI images (5). Additionally, a k-space method has been proposed to correct for respiration-induced phase and frequency fluctuations using phase information from the centre of k-space (6). In this work, we investigate how cardiac pulsatility and respiration affect both phase and magnitude data constructed from a standard EPI sequence. Previously, we have used phase information to estimate susceptibility effects caused by head motion (7). Here we expand on this idea to characterise cardio-respiratory effects in phase data.

**Methods:** Images were acquired on a head-only 3T scanner (Allegra, Siemens Medical, Erlangen, Germany), matrix=64x64, resolution=3x3mm, slices=64, thickness=2mm+1mm gap, TE=30ms, slice TR=65ms. Three healthy consenting subjects were scanned for two runs of 100 image volumes (total scanning time of ~14 mins). The subjects were asked to pay attention to their breathing, keeping it at a constant rate with a slightly increased depth. Cardiac pulse and respiratory phase were monitored using pulse-oximeter and respiratory belt. Magnitude and phase images were constructed from EPI raw data. The magnitude images were realigned to the first image in the time series using a rigid body model as implemented in SPM5 (8). The resulting head motion parameters were used to resample each phase image in the space of the first image accounting for spatio-temporal phase discontinuities. Cardio-respiratory effects were modelled as 5 and 3 harmonics (sine and cosine pairs) of the measured cardiac and respiratory signal respectively, as described in (2-4), the respiration volume per time as described in (5) and 6 motion parameters, giving a total of 23 regressors. Using SPM5 (8), the magnitude and phase data were smoothed using a 6mm Gaussian kernel and analysed to determine where in the brain the temporal variance was best explained by the different regressors. For each subject, a map of the F statistic was calculated for phase and magnitude data for cardiac effects (thresholded at an uncorrected p-value of 0.001) and respiratory effects (both respiratory phase and volume per time, thresholded at a corrected p-value of 0.05). The regressors associated with head motion were also included in the model but the associated statistical maps were not of interest in this work.

**Results:** The results from a single subject are shown and are typical for all 3 subjects. The two left images show the map of the F statistic for cardiac effects in magnitude and phase data. Note that the variance explained by the cardiac regressors has a similar spatial structure in the phase and magnitude images, particularly in the region of increased vasculature in lower regions of the brain. However, the effect is smaller in the phase images. The two right images show the map of F statistic for respiratory effects. In the magnitude images, variance is mostly explained by respiratory effects around edges. In contrast, respiratory effects caused widespread phase changes with an observed gradient in head-foot direction.




**Discussion:** The experimental results illustrate the characteristics of cardio-respiratory effects on the phase in EPI and their comparison with the same effects on the magnitude in EPI. Statistical maps show that both the phase and the magnitude data are strongly affected. Previously proposed image-based methods for correcting physiological sources of noise in fMRI are mainly based on the correlation between cardio-respiratory effects and the magnitude time courses (2-4). Although effective, care must be taken when using these methods that true signal is not removed, especially when a task is time-locked to cardiac function or respiration. From the presented results we conclude that the development of robust physiological noise correction methods could benefit from using EPI phase information, in particular, since phase and magnitude data are differentially affected by cardio-respiratory effects. For example, one approach may involve an extension of the phase-informed model presented in (7).

**References:** **1.** Ogawa S, et al. Proc Natl Acad Sci U S A 1990;87(24):9868-9872. **2.** Josephs, O, et al. Proceedings of the 5th Annual Meeting of ISMRM, Vancouver, Canada: 1997.**3.** Glover GH, et al. Magn Reson Med 2000;44(1):162-167. **4.** Lund TE, et al. Neuroimage 2006;29(1):54-66. **5.** Birn RM, et al. Neuroimage 2006;31(4):1536-1548. **6.** Pfeuffer J, et al. Magn Reson Med 2002;47(2):344-353. **7.** Hutton, C, et al. 11th Annual OHBM, Toronto: 2005. **8.** Friston, K, et al. London: Elsevier Ltd; 2007.

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