A continuous Nyquist ghost correction for EPI-based fMRI

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Introduction

Nyquist ghosting, which can be present in EPI data even after correction with a non-phase encoded reference scan, not only represents a reduction of the image signal, but it can also result in false positive activation in fMRI datasets. Eliminating the Nyquist ghosting is thus expected to improve the reliability of the brain activation maps. Ghosting is caused by a frequency offset *Δf(x,y)* [1], which depends on k_y as well as k_x. This implies that using a 'negative gradient read-out' strategy, where a phase encoded reference scan is acquired with reversed polarity of the read-out gradient (G_x), is expected to lead to further artefact reduction [1]. The aim of the present study was to establish such a negative readout strategy on a clinical 7 Tesla scanner and to assess its impact on fMRI activation studies.

Methods

Data acquisition: An oil phantom and six right-handed volunteers were scanned on an actively shielded 7T/68cm Siemens scanner with head gradient coil. A modified EPI sequence was used for fMRI data acquisition: complex data was saved and the read-out direction was alternated every other volume. EPI data acquired with a first read-out gradient amplitude of G_x are referred to as 'positive' and data acquired with a first read-out gradient amplitude of $-G_x$ are referred to as 'negative'. Three ghost correction schemes for fMRI are described in Table 1. For the phantom experiments, 10 volumes were acquired using the fMRI scan parameters, with bandwidths of 2442 and 1954 Hz/pixel to study the performance of the ghost correction schemes at different echo spacing times as this partially determines ghosting levels.

fMRI data were acquired with a 64 x 64 matrix and an in-plane resolution of 3 x 3 mm^2. 20 transverse, 3.8 mm thick slices, with phase encode direction L-R, were acquired every 2 seconds. TE/α/bw was $27ms/80^0/1954$ Hz/pixel. The block paradigm consisted of an 8s ON-period followed by an OFF-period of 20s and was repeated 6 times. During the ON period, subjects performed a digit-opposition task with all fingers of the left hand. In a second experiment, subjects were asked to swallow during the finger tapping task, introducing task-correlated motion.

	Method	fMRI temporal resolution retained ?	% remaining ghost in phantom (BW = 1954)	% remaining ghost in phantom (BW = 2442)	% remaining ghost in subject data	average maximum T-score in M1
Scanner data			4.9 %	2.9 %	5.0 ± 1.1 %	14.1 ± 3.5
P: Phase difference	fft_x, phase correction using ½ phase difference between positive and negative data, fft_y	Yes	2.1 % (59 % reduction)	1.1 % (60 % reduction)	2.9 ± 0.9 % (40 ± 11 % red.)	15.3 ± 2.4
A: complex Addition	fft_x, summation of positive and negative data, fft_y	No, timecourses are filtered with a running average of 2.	0.2 % (96 % reduction)	0.3 % (90 % reduction)	1.9 ± 1.1 % (62 ± 18 % red.)	15.4 ±1. 9
CP: Corrected Phase	fft_x, summation of positive and negative data, combination of the phase of the sum with the 'positive' or 'negative' amplitudes, fft_y	Yes	1.8 % (63 % reduction)	1.1 % (60 % reduction)	3.1 ± 1.1 % (37 ± 13 % red.)	17.3 ± 2.9

Table 1. Ghost correction methods and results. Fft_x and fft_y indicate Fourier transforms along read and phase-encode dimensions, respectively.

Analysis: Ghost corrections as described in Table 1 were applied to all datasets. Using signal, ghost and noise ROI's, ghost levels were calculated for each dataset as: $\left(S_{ghost}/S_{signal} - S_{noise}/S_{signal}\right)*100$.

Subsequently, data was realigned and spatially and temporally filtered using SPM5 (FIL, UK). SPM's were formed for each fMRI data set (P_{corr} <0.05). T-scores and the size of the active region were measured in each dataset.

Results and Discussion

The result of the ghost corrections is given in Table 1. All 3 methods consistently improved ghosting levels in the phantom data. In the fMRI data, activation was found for all subjects in contralateral M1, PMA and ipsilateral M1. Motion related with the swallowing task was found for all subjects. The resulting translation of 0.3 ± 0.2 mm did however not result in false-positive activation in the ipsilateral cortex. All three continuous ghost correction schemes reduced Nyquist ghosting in fMRI data significantly, without a significant change in number of active voxels in either M1 or PMA. Data from a representative subject is shown in Fig. 1. A small increase in maximum T-scores was found using scheme CP (See Table 1). This means that while no actual false positive activation was found, some BOLD signal is lost due to Nyquist ghosting which can be regained using a correction scheme as described here. The correction scheme suggested here is likely to improve the reliability of fMRI data sets affording a continuous correction without an increase in scan time or loss of temporal resolution and can be combined without further development with parallel imaging or conventional fieldmap based unwarping of EPI data.

Conclusion

While the best ghost reduction is achieved with the complex summation scheme A, the use of the scheme CP results in higher T-scores as the temporal resolution of the fMRI data is better preserved.

References 1. Hu. et al. Magn Reson Med. 1996 Jul;36(1):166-71.

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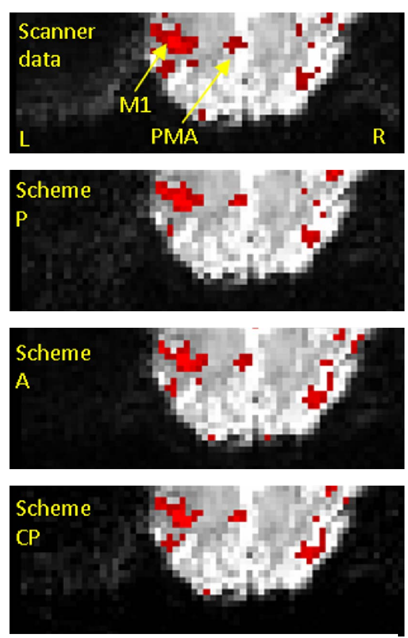

Figure 1. Activation maps from a representative subject are shown overlaid on fMRI data. Ghost suppression is most complete using Scheme A.