Removal of EPI Ghosts in the Presence of Prospective Motion Correction

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Purpose: EPI ghost correction often involves the acquisition of calibration data at the beginning of the scan with phase encoding turned off. While this method works well in most cases, it does not handle a scenario where the gradient axes are rotated during the scan. One such scenario is when prospective motion correction [1-3] is used: the gradient axes are rotated so that the scan plane follows the head motion. The alteration of gradient axes causes readout, slice-select or phase encoding to use multiple physical gradient coils simultaneously, which results in a different delay between even and odd lines after rotation, partially invalidating the initial ghost calibration [4]. In this case, a more robust technique that performs EPI ghost calibration individually for each EPI readout might be required. In this study, we compared three different techniques in order to assess the importance of performing EPI ghost correction individually for each readout.

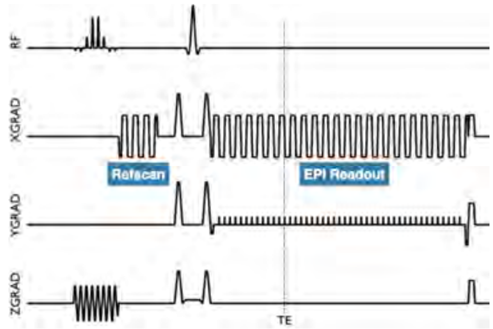

Figure 1 The EPI sequence used for this study. The refscan portion consists of 6 lines with no phase encoding and is used to estimate ghost parameters for each slice at each time point.

Methods

Prospective Optical Motion Correction: An MR-compatible camera was mounted on the head coil, as described in [2]. The camera tracks a visual checkerboard marker on the patient's forehead. The video signal from the camera is transmitted to a laptop. The camera images of the marker are processed by the laptop, and motion parameters are sent in real-time to the scanner via a network buffer. On the scanner side, the motion parameters are read from the network buffer and the scan plane is updated accordingly. Therefore, any rotations that occur result in an update of the gradient axes such that readout, slice-select or phase encoding use multiple physical gradient coils simultaneously.

EPI Scan: A dynamic spin-echo single-shot EPI scan was performed at a 3T GE 750 scanner. Scan parameters were: TR=3000ms, TE=27ms, FOV=24cm, 64x64 in plane resolution, partial Fourier imaging with 12 overscans, ramp sampling turned on, 20 dynamic time points. An additional readout was performed right after the RF excitation to serve as a 'refscan' – for each readout – for EPI ghost correction method (Fig. 1). This refscan consisted of 6 lines of EPI readout with phase encodes turned off. The volunteer was asked to perform continuous head shaking motion throughout the scan, and prospective motion correction was turned on.

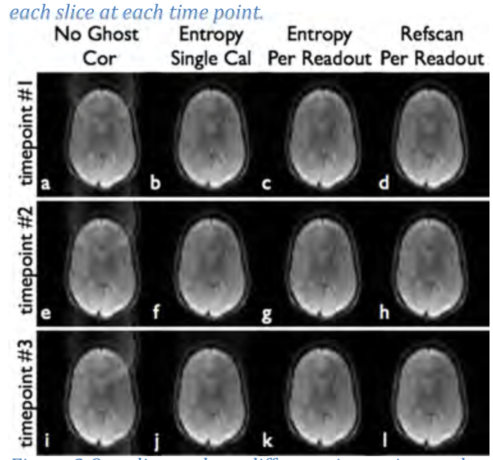

Figure 2 One slice at three different time points and reconstructed using three different ghost correction algorithms. Time points are shown in Fig. 4

Ghost Correction: Three different techniques were used for EPI ghost correction:
Entropy (Single Cal): Entropy-based ghost correction was used to estimate ghost parameters from the first volume in the time series [5]. These ghost parameters were applied to the other volumes in the acquisition. This scenario resembles the case wherein a calibration scan is used at the beginning of the acquisition and is applied to all other volumes, which is commonly used in GE MRI scanners.
Entropy (Per-Readout): Entropy-based ghost correction was used to estimate and correct EPI ghosts separately for each time point and each slice.
Refscan (Per-Readout): Ghost parameters were estimated from the short refscan acquired at each slice and time point and applied subsequently during image reconstruction. The refscan consisted of 3 even and 3 odd lines with no phase encoding, which were averaged to increase SNR. After averaging even and odd lines separately, the 1D k-space was Fourier transformed, and the constant and linear phase terms that yielded the best match between the even and odd lines were determined. This method is the default technique used by the Siemens MRI platform.
The signal energy outside of the brain volume (i.e. ghost energy) was used as a metric to quantify the performance of each ghost correction method.

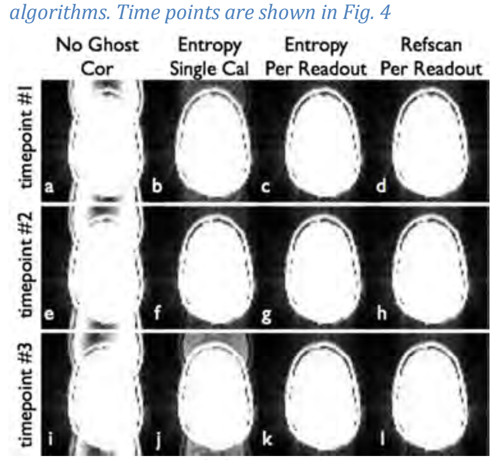

Figure 3 Intensity-scaled version of Fig. 2

Results: Figure 2 shows one slice at three different time points and reconstructed using three different ghost correction algorithms and Fig. 3 shows the same images after being intensity-scaled by 10x. The three time points corresponding to each row in Figs 2 and 3 are shown in Fig. 4. The images reconstructed with no ghost correction are also shown. As expected, the ghosts are clearly visible in the non-scaled images (Fig. 2, first column) if ghost correction is not applied. The images reconstructed with any of the ghost correction methods show reduced ghosting artifacts (Fig. 2, columns 2,3,4). As expected, the scaled images demonstrate that using a single calibration scan results in residual ghosting when gradient axes are rotated in response to detected motion, as in the case at time point #3 (Fig 3j). Performing a per-readout ghost correction using either entropy or refscan successfully removes this residual ghosting (Fig. 3k,l). Fig. 4 shows that ghost energy is lower when per-readout ghost correction is used as opposed to using a single calibration. It can also be seen in Fig. 4 that the difference between using a single calibration and per-readout correction becomes more pronounced when the motion is larger (Fig. 4, black solid line and time point #3).

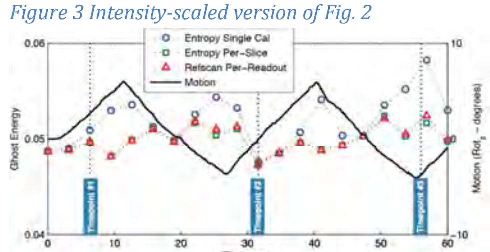

Figure 4 Ghost energy obtained using three ghost correction methods for each time point and for the slice shown in Fig. 3. (dotted lines). z-component of the rotational motion is also shown (solid line).

Discussion & Conclusion: Our results show that in the presence of real-time gradient updates, performing EPI ghost correction individually for each readout yields better ghost suppression than using a single ghost calibration at the beginning of the scan. The additional calibration scan shown in Fig. 1 performs per-readout ghost correction, but has the disadvantage of increasing the echo time in diffusion scans. Entropy-based per-readout calibration circumvents this shortcoming at the cost of longer reconstruction times.

References: [1] Zaitsev et al, Neuroimage, 2006 [2] Aksoy et al, Magn Reson Med, 2012 [3] Maclaren et al, PloS ONE, 2012. [4] Gibbons et al, ISMRM, 2012 [5] Skare et al, ISMRM, 2006 **Acknowledgements**: NIH (2R01 EB00271108-A1, 5RO1 EB008706, 5R01 EB01165402-02), the Center of Advanced MR Technology at Stanford (P41 EB015891), Lucas Foundation, Oak Foundation, GE Healthcare.