# Autocorrection for EPI Ghost Intensity Reduction

**Heidi A. Ward**[1], Armando Manduca[1], Stephen J. Riederer[1], Clifford R. Jack Jr[1]
[1]Mayo Clinic, MR Research Center, Rochester, MN USA;

## Introduction

Fast scanning techniques such as Echo Planar Imaging (EPI) suffer from Nyquist ghosts due to signal discontinuities between even and odd echoes. Reference scans are commonly used to offset phase errors between even and odd echoes [1]. A fundamental limitation of reference scans is that they are acquired once prior to the EPI acquisition for the prescribed imaging orientation. The reference scan method therefore cannot correct for changes that occur during EPI scanning itself, limiting the effectiveness of ghost reduction for dynamic real-time scanning, such as neuro-functional MRI (fMRI).

FMRI studies in particular are extremely sensitive to signal instability over time. Since global head motion is a major source of signal instability, prospective motion correction schemes have been introduced in which the scan plane is dynamically altered to track with the subject´s head [2-4]. However, alteration of the scan plane orientation itself causes fluctuation in both ghost intensity and distribution [5], potentially affecting detection of functional activation.

To address the problem of dynamic changes in even-odd echo alignment and spacing during EPI, we are investigating an alternative ghost reduction scheme. Autocorrection, a method of iteratively applying phase corrections to raw data and assessing image improvement from an image-based metric, has been shown to reduce view-to-view motion artifacts in several clinical applications [6,7]. Modifications of the autocorrection algorithm to instead apply phase corrections specific to EPI could potentially provide an effective method of Nyquist ghost reduction for each individual image in a time series. The purpose of this study was to evaluate whether the autocorrection method was capable of reducing Nyquist ghosting, assess the stability of autocorrection over time, and also assess the ability of autocorrection to reduce ghosting in the presence of dynamic changes in scan orientation.

## Methods

Three experiments were performed to test the benefit of autocorrection for EPI ghost reduction. For all experiments, the autocorrection algorithm corrected two parameters commonly known to induce Nyquist ghosts in EPI: even-odd echo alignment in the frequency-encoding direction and even-odd echo spacing in the phase-encoding direction [5]. Processing was performed independently first for echo alignment, and then for echo spacing. Entropy, which seeks to maximize the black areas in an image, was used as the image-based metric. A uniform, spherical phantom was imaged.

The purpose of Experiment 1 was to evaluate the ability of autocorrection to reduce ghosts, and to compare autocorrection with the reference scan correction method. 27 5mm thick 64x64 single-shot EPI (ssEPI) images were acquired, with corresponding reference scans. Images were reconstructed off-line, both with and without reference scan correction. Raw uncorrected and reference scan corrected data was used as input to the autocorrection algorithm. The ghost-to-image intensity ratios for the four methods of reconstruction (uncorrected, reference scan corrected, autocorrected, and both reference scan and autocorrected) were used to compare the degree of ghost reduction.

The purpose of Experiment 2 was to measure the temporal stability of EPI time-series data that was reconstructed with and without autocorrection. Serial sagittal ssEPI images were acquired continuously over 20 minutes. After reconstruction, the signal variance over time was calculated for each pixel in the image. The average signal variance within the image was used to compare the methods of reconstruction.

The purpose of Experiment 3 was to compare the variation in Nyquist ghosting for reference scan correction and autocorrection as the imaging plane was rotated away from the baseline position. Axial ssEPI images were acquired for various rotations about the z-axis, such that the frequency- and phase-encoding logical gradients were combined on the physical gradient amplifiers.

## Results

Figure 1 shows the average ghost-to-image intensity ratios for all image slices in Experiment 1. Autocorrection of the original data performed as well as the reference scan, and autocorrection provided a slight improvement for the reference scan corrected data. On a slice-by-slice basis, the ghost-to-signal intensity ratio of the reference scan correction varied by as much as 60% whereas the autocorrected images varied by only 20%. Thus, the ghosting properties of the autocorrected scans are more uniform across the volume.

In Experiment 2, autocorrection reduced the average signal variance by 15% over the uncorrected image series. Figure 2 shows the record of echo alignment values determined by the autocorrection algorithm for two slices. Note a slow drift in echo alignment over time, which would have been missed by the reference scan method.

Experiment 3 showed that autocorrection produced lower ghost-to-image intensity and greater uniformity across scan orientations than either uncorrected or reference scan corrected data. Figure 3 shows the ghost-to-image intensity ratios plotted against the rotation angles for each case. Inspection of cine loops of the data from Experiment 3 also showed the ghosts in the original images to undergo large changes in spatial distribution of ghost intensity, whereas the autocorrected images had more spatially uniform ghosts over varying rotation angles.

## Discussion

In this initial implementation of autocorrection for EPI ghost reduction, we allowed only two parameters to vary. Improvements could be made, such as allowing parameters to vary for each line of k-space, or modeling additional effects known to cause EPI ghosting. However, even with this simplistic implementation, the method performed as well as, if not better than, the reference scan correction. Currently, since a single parameter is applied either to all even or odd echoes, each image was split into two image data sets consisting of either even or odd echoes. After phase correction, the images were combined for evaluation of the image based cost function. Thus, only two FFTs were required per image, and the autocorrection algorithm converged to a minimum within 30 msec with non-optimized code on a standard computer.

In conclusion, the initial implementation of autocorrection for EPI ghost reduction performs as well as the standard reference scan correction, and is more stable over time and with dynamic changes in image orientation. Thus, it should be beneficial to dynamic scanning techniques, especially those dependent on signal stability over time.

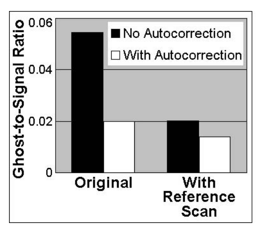


**Figure 1**

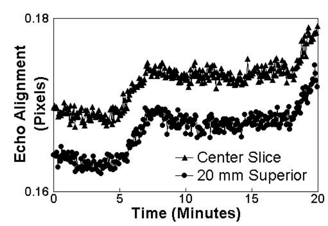


**Figure 2**

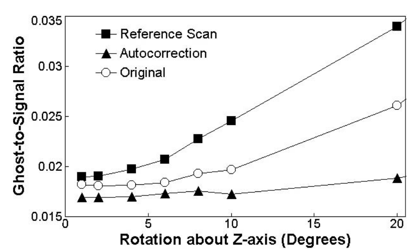


**Figure 3**

## References

1. JK Maier, et al. US Patent #5151656, 1992.
2. HA Ward, et al. Magn Reson Med 2000;43:459-469.
3. S Thesen, et al. Magn Reson Med 2000;44:457-465.
4. JA Derbyshire, et al. JMRI 1998;8:924-932.
5. X Zhou and JK Maier. Proc. of ISMRM 4th Meeting 1996;386.
6. A Manduca, et al. Radiology 2000;215(3):904-9.
7. D Atkinson, et al. Magn Reson Med 1999;41:163-170.