Parallel Imaging with Asymmetric Acceleration (ASYA) to Reduce Susceptibility Artifacts in BOLD fMRI

K-J. Jung[1], and T. Zhao[2]

[1]Scientific Imaging Brain Research (SIBR), Department of Psychology, Carnegie Mellon University, Pittsburgh, PA, United States, [2]MR R&D Collaborations, Siemens Medical Solutionsn USA, Siemens Healthcare, Pittsburgh, PA, United States

Parallel imaging with acceleration reduces geometric distortion with increased slice coverage at a given repetition time (TR) of the gradient echo EPI sequence. However, it is noted that the parallel acceleration pronounces the truncation artifact, i.e., the ripple artifact, near the susceptibility-affected region (Chen, at al. 2006). The reason of the pronounced ripple artifact was studied using the extended EPI sequence (Jung, et al. 2010) and a new EPI sequence was developed to reduce the ripple artifact in this abstract.

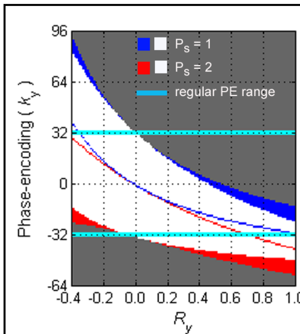

Fig. 1. Echo shift by R_y.

Methods: The echo shift from the center (k_y=0) of the regular data acquisition (DAQ) window, i.e., Δk_y, can be estimated as $\Delta k_y = -(T_E/T_{ESP})[P_sR_y/(Ps+R_y)]$, where P_s denotes the symmetric parallel acceleration factor, Ry ($=\partial\Delta B_0/\partial y/g_y$) is the y-directional in-plane susceptibility gradient (ISG_y) in the unit of the applied PE gradient g_y, T_E is the echo time, and T_{ESP} is the echo spacing time. It is very interesting to note that Δk_y at P_s = 2 deviates more into the pre-T_E period than that at P_s = 1 in particular at positive R_y as shown in Fig. 1.

The gradient echo EPI sequence was modified to extend the data acquisition to outside of the regular DAQ window (Jung, et al. 2010). The ripple artifact was compared among images that were reconstructed without and with an inclusion of the signals acquired in the pre- and/or post-T_E period.

From the theory and experimental results, the ripple artifact was analyzed and found to be caused by an effectively pronounced echo shift in accelerated parallel imaging, particularly in the pre-T_E period. Therefore, the EPI sequence was designed to apply parallel acceleration asymmetrically only to the post-T_E period. At 3T the optimum T_E for the BOLD sensitivity is about 30 ms or longer. Therefore, there was enough time for the non-accelerated EPI readout to be applied in the pre-T_E period. Furthermore, the extended readout can be applied in the pre-T_E period to further reduce the signal loss and the ripple artifact due to magnetic field susceptibility. The pulse sequence of the proposed ASYA method is shown in Fig. 2 for a 64x64 image matrix and other timing specifications of a whole body 3T scanner.

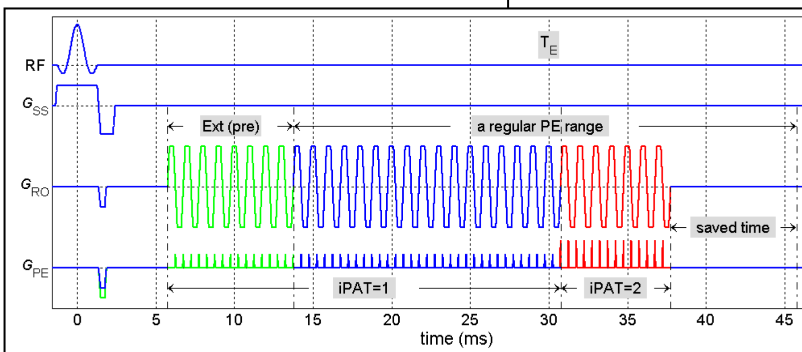

Fig. 2. Pulse sequence diagram of the proposed ASYA method.

Results: There was ISG_y in the sphere phantom around the trapped air (Fig. 3). The ripple artifact was more pronounced at P_s=2 than at P_s=1 in both the phantom and the head images (green arrows in Figs. 4 & 5). The ripple artifact was removed by including both sides of the extended data (column Ext-LR). The ripple artifact was strongly reproduced when the extended left side (pre-T_E) was filled with zero in the image reconstruction (see the region noted by red arrows in the Ext-R column of Figs. 4 & 5). The extended right side (post-T_E) contributed less to the ripple artifact due to an increased T2* weighting at the post-T_E period. With the proposed ASYA sequence, the ripple artifact was significantly suppressed at the asymmetrical acceleration factor (P_{as}) of 2 for both the phantom and the head (3rd row, 1st column in Figs. 4 & 5). Furthermore, the noise level in the background, which was increased at P_s=2 (noise mean=114) compared to that of P_s=1 (noise mean=114), was also suppressed at P_{as} =2 (noise mean=97) to a similar level of that at P_s=1.

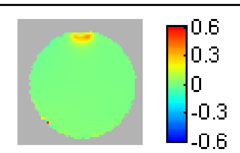

Fig. 3. ISG_y map (unit: g_y).

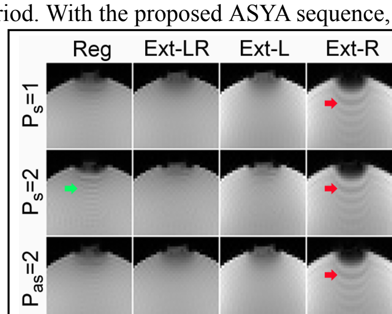

Fig. 4. Images of a sphere phantom.

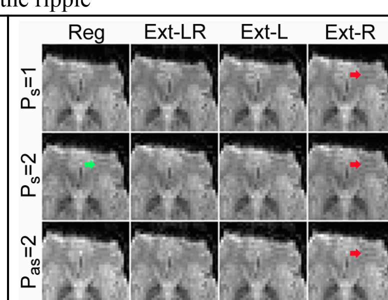

Fig. 5. Images of a volunteer's head.

Conclusions: The ripple artifact is pronounced in accelerated parallel imaging due to the increased echo shift toward the pre-T_E period by positive ISG. The ripple artifact can be reduced using the proposed ASYA sequence without sacrificing the slice coverage. Furthermore, the proposed ASYA sequence can restore the signal-to-noise ratio that is compromised at the accelerated parallel imaging.

References: Chen NK, et al. (2006): Neuroimage 31(2):609-22. Jung KJ, et al. (2010): Magn Reson Imaging 28(6):777-83.