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

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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, et 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.

Methods: The echo shift from the center (kₜ–0) of the regular data acquisition (DAQ) window, i.e., Δkₜ, can be estimated as Δkₜ = -(Tₑ/TESP)(PₛRₛ/(Ps+Rₛ)), where Pₛ denotes the symmetric parallel acceleration factor, Rₛ is the y-directional in-plane susceptibility gradient (ISGₛ) in the unit of the applied PE gradient gₛ, Tₑ is the echo time, and TESP is the echo spacing time. It is very interesting to note that Δkₜ at Ps = 2 deviates more into the pre-Tₑ period than that at Ps = 1 in particular at positive Rₛ 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-Tₑ 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-Tₑ period. Therefore, the EPI sequence was designed to apply parallel acceleration asymmetrically only to the post-Tₑ period. At 3T the optimum Tₑ 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-Tₑ period. Furthermore, the extended readout can be applied in the pre-Tₑ 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.

Results: There was ISGₛ in the sphere phantom around the trapped air (Fig. 3). The ripple artifact was more pronounced at Pₛ=2 than at Pₛ=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-Tₑ) 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-Tₑ) contributed less to the ripple artifact due to an increased T₂* weighting at the post-Tₑ period. With the proposed ASYA sequence, the ripple artifact was significantly suppressed at the asymmetrical acceleration factor (Pₛₛ) 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 Pₛ=2 (noise mean=114) compared to that of Pₛ=1 (noise mean=114), was also suppressed at Pₛₛ = 2 (noise mean=97) to a similar level of that at Pₛ=1.

Conclusions: The ripple artifact is pronounced in accelerated parallel imaging due to the increased echo shift toward the pre-Tₑ 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 compromized at the accelerated parallel imaging.