Employing Bootstrapping Methods to Examine the Need for Pulse Triggering In Diffusion-Weighted Imaging

Z. Nagy[1], C. Hutton[1], D. C. Alexander[2], R. Deichmann[1,3], and N. Weiskopf[1]

[1]Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, London, London, United Kingdom, [2]Centre for Medical Image Computing, Department of Computer Science, University College London, London, London, United Kingdom, [3]University Hospital Brain Imgaging Centre, University of Frankfurt, Frankfurt, Germany

Introduction: The effect of diffusion on the MR signal was first described by Carr and Purcell (1). Later Le Bihan introduced diffusion encoding gradients into an imaging sequence (2) according to Stejskal and Tanner (3). As a diffusion-weighted sequence is sensitive to movement on a micrometer scale, any movement at that or a higher scale has the potential for causing artefacts. For example the pulsatile movement due to each heartbeat was demonstrated to increase the variance in the diffusion weighted images (4). Accordingly, many research and clinical sites now routinely employ pulse triggered diffusion-weighted acquisition techniques where the data collection occurs between heart beats only. However, this method substantially prolongs the acquisition time and hence whether pulse triggering is universally necessary should be re-examined. The aim of this study was to develop a protocol, employing bootstrapping methods, to compare the variance between sets of images that were acquired with and without pulse triggering.

Methods: ***Data acquisition:*** All experiments were performed on a 1.5T scanner (Magnetom Sonata, Siemens Medical Erlangen, Germany). Images were acquired with 2.3mm^3 resolution, 30 slices with 1.15mm interslice gap, 96x96 matrix, TE was 90ms. Two experiments were carried out on an adult, human subject. For each experiment 2x40 image volumes were collected. To maximise the sensitivity to pulsatile brain movement, a single diffusion encoding direction along the positive z gradient axis was used. In experiment 1, images were collected alternately with b=100 or 1000 s/mm^2, resulting in 20 reference images and 20 DWIs. In experiment 2, only every 8th image was acquired with b = 100 s/mm^2 resulting in 5 reference images and 35 DWIs. In both experiments the acquisition was repeated twice; (a) pulse triggered using a 500ms trigger delay while acquiring a single slice per heartbeat and (b) without triggering but with the slice-to-slice TR set so that the total acquisition time was identical to that with pulse triggering.

Image analysis: Before any analysis the images were examined by eye and slices with obvious movement or k-space spike artefacts were removed (a maximum of 3). In experiment 1 we addressed the question whether the reference images or the DWIs contribute more to the variance in the resulting ADC images. Therefore 20 ADC images were calculated in two different ways. First the 20 reference images were averaged and an ADC image was calculated for each of the 20 DWIs. Or the 20 DWIs were averaged and an ADC image was calculated for each of the 20 reference images. In experiment 2 the mean of the 5 reference images was used to calculate an ADC image for each of the 35 DWIs and bootstrapping was employed to investigate whether the variance in the ADC images was lower when pulse triggering was employed. The bootstrapping algorithm was a straightforward application of the theory as developed by Efron (5). Two pseudo groups were generated by randomly selecting from the 2x35 ADC images. One pseudo group represented the pulse triggered and the other the non-pulse triggered acquisition. The ratio of variances between the two pseudo groups was calculated and stored for 8000 repetitions of this procedure. Finally, the ratio of variances between the two original groups was compared to the distribution of the 8000 repetitions in order to calculate a p-value. We also used the Camino (6) software package to generate fibertracks from 4 ROIs placed in the genu and splenium of the corpus callosum and the left and right cortico-spinal tracks. The lengths of the fibres were calculated and stored.

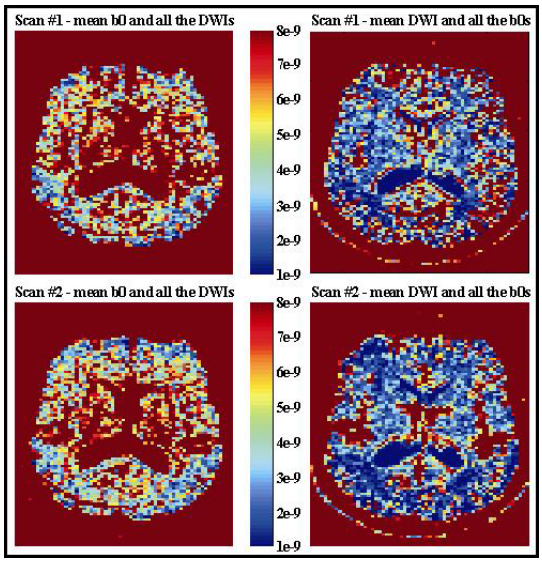

Figure 1 – Variance in ADC images

Results: Figure 1 displays 4 ADC variance images from experiment 1. The top and bottom rows are with and without pulse triggering respectively. The left column contains images where the 20 reference images were averaged and an ADC image was calculated for each of the 20 DWIs. The right column contains images where the DWIs were averaged and an ADC image was calculated for each of the 20 reference images. Higher variance results in the ADC images due to the signal variation in the DWIs (left column). Note that the difference in variance with or without pulse triggering (within the columns) is significantly less.

The results of the bootstrap analysis based on experiment 2 are displayed in Figure 2. The ratio of the original variances was compared in each voxel to the histogram of those generated from the 8000 re-samples. The voxels with $p<0.0005$ (not corrected for multiple comparisons) are shown overlaid on a b0 image in lower slices where pulsatile effects have been observed (4).

The employment of pulse-triggering did not produce consistent differences in the lengths of trackable fibres. There were no visually discernable differences either.

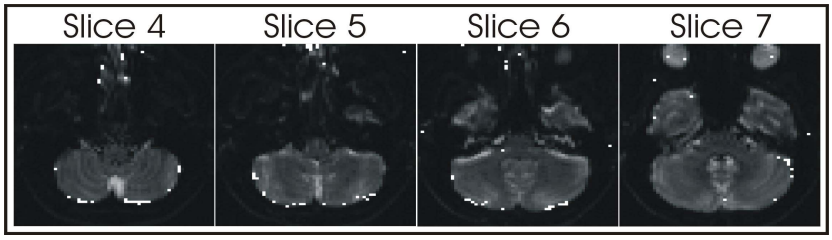

Figure 2 – voxels with p < 0.0005 overlaid on a b0 image

Discussion: Various studies used pulse triggered acquisition of diffusion-weighted datasets to avoid pulsatile artefacts. However, the present results suggest that acquiring DWIs without pulse triggering does not sgnificantly reduce the quality. For our scanner/sequence setup, voxels profiting from pulse triggering occur mostly at edges or outside the brain and do not indicate bulk movement of the tissue due to pulsation as observed previously in (4). It must be emphasized, however, that the results here should not be generalized to all scanners and research projects. For example, Robson and Porter (7) showed that the reconstruction method influences the amount of pulsation artefacts in diffusion weighted images. Also, pulsation artefacts may be more prominent in certain patient groups. The method presented here can be implemented easily at each research/clinical site with a sample of the general subject population to determine the need for pulse triggering locally.

References

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