An Efficient Method for Acquiring Cardiac-Gated Diffusion-Weighted Images

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Introduction:

Diffusion-weighted (DW) images are inherently very sensitive to motion. The pulsatile motion of the brain, particularly during systole, can give rise to additional signal attenuation and thus to an over-estimation of the apparent diffusion coefficients [1]. Such miscalculations can in turn lead to erroneous estimates of the principal eigenvectors [2]. Cardiac gating can be performed so that data will be only acquired during the quiet portion of the cardiac cycle [3]. Although effective, this approach does lead to a significant increase in the acquisition time. It has also been demonstrated that the velocity gradients that cause these artefacts are not significant in regions of the brain above the *corpus callosum* [1,3]. To improve the efficiency of cardiac gated acquisitions, we therefore propose a new scheme whereby a greater number of slices can be scanned per cycle provided that the upper slices of the brain are acquired during systole.

Methods:

Data were acquired on a 3.0 T Varian Inova scanner. A birdcage radio-frequency head coil was used for both pulse transmission and signal detection. The diffusion gradients achieved a maximum strength of 21.3 mT/m. Three data sets were acquired on one subject: non-gated, gated using the optimised method and gated using the standard method [3]. For the latter, three slices were acquired per cycle in order to avoid systole. For the optimised scan, the order in which the slices were acquired was adjusted to ensure that the upper slices of the brain would be scanned during systole. The number of slices scanned per cycle was set depending on the maximum estimated heart rate, so as to minimise the acquisition time. The total number of slices could also be increased from a minimum of 45 so as to be a multiple of the number of slices acquired per cycle. In both the optimised and the traditional cardiac gating schemes, gating was performed such that triggering occurred in every cycle
For both the non-gated and standard gated method, the slices were ordered in an interleaved manner to avoid cross-talk effects. The slice thickness was 3.0 mm. The other acquisition parameters were: TE= 106 ms, bandwidth of 125 kHz, field of view of 240×240 mm^2, matrix size of 96×62 (half K-space acquisition) interpolated to 128×128. The repetition time for the non-gated data was set to the minimum possible (TR= 8.6 s for 45 slices). Each data set consisted of 40 DW images with the diffusion gradients applied along the zz (through slice) direction. The b-value was set to 1000 s/mm^2.
To correct for motion all data sets were re-aligned to a non-DW image using an affine registration method [4]. To check for the presence of artefacts, the standard deviation of the signal in each pixel was calculated over the 40 volumes. An F-test was performed to compare the variability observed with each of the three methods. The threshold for the F-maps was set to F=5.5 corresponding to a Bonferroni corrected p-value of 0.05 (number of voxels ~ 186 k).

Results:

The acquisition times measured for the three methods are shown in Table 1. The acquisition time for the optimised scheme was only slightly longer than the minimum necessary (non-gated approach). The scanning efficiency using the optimised method was significantly improved when compared with the previously suggested method [3], allowing for a significantly higher signal-to-noise to be achieved per time unit.

Approximate Heart Rate (bpm)	Slices per RR	Number of Slices	Acquisition Time (min)			Scanning Efficiency (%)	
			Non-gated	Optimised Scheme	3 Slices per RR	Optimised Scheme	3 Slices per RR
52	5	45	5min44s	6min57s	11min58s	82	48

Table 1 – Acquisition times measured for the three acquisitions. Also shown is the scanning efficiency of both gating schemes compared to the non-gated approach.

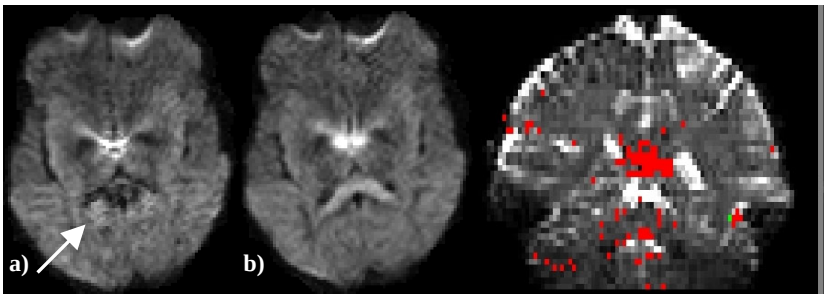

Figure 1 – a) Image displaying artefact due to pulsatile motion (white arrow). **b)** Same slice imaged with the optimised gating scheme.

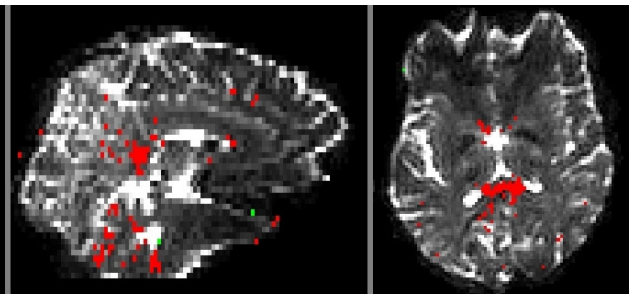

Figure 2 –Thresholded F-maps superimposed on a non-DW image. In red, voxels where the variance is significantly greater in the non-gated data set compared to the standard gating method. The small number of voxels where the optimised scheme lead to a significantly higher variance than the standard gating approach are shown in green.

On Figure 1 an example of an image which displayed pulsatile artefacts is shown together with the corresponding image acquired with the optimised gated scheme. The presence of such artefacts was detected by calculating the signal variance over the 40 volumes acquired. As can be seen from the F-maps on Figure 2, increased variance was detected for the non-gated data set, particularly on regions of the brain below the corpus callosum, when compared to the standard gated acquisition. No significant differences were observed when comparing the two kinds of gated acquisitions.

Discussion and Conclusions:

Despite being known to improve the quality of the data [1-3], the long acquisition times and reduced scanning efficiencies associated with traditional methods of cardiac gating have deterred many researchers from applying it. Using the new optimised method, artefact-free images can be obtained without having to prolong significantly the total acquisition times.
An important issue when performing cardiac gating is the variation in T_1 weighting due to fluctuations of the subject's heart rate. Given, however, that for a whole brain acquisition a long TR can be used without loss of efficiency, such fluctuations should be insignificant. In the approach described the effective TR was always at least 8.6 s, which is significantly higher than the average T_1 in human brain white matter at 3.0 T (860 ms) [5].
In summary, we have presented a new optimised method to acquire cardiac-gated DW images. Using this approach, artefact-free images can be acquired at a very small cost in acquisition time, when compared with more artefact prone non-gated acquisitions.

References: [1] WIRESTAM et al., *JMRI*, 1996; **6**: 348. [2] PIERPAOLI et al., *ISMRM*, 2003; 70. [3] SKARE et al., *MRI*, 2001; **19**:1125. [4] JENKINSON et al., *NeuroImag*, 2002; **17**: 825 [5] CLARE et al.; *MRM*, 2001, **45**:630