Relevance of Cardiac-Gating in Longitudenal Diffusion Weighted MRI Studies

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Introduction

Considerable effort has recently been invested to determine the necessity of cardiac-gating DWI-acquisitions. While some groups have demonstrated the presence of attenuation artifacts whose nature, position and frequency suggests their origin lies in cardiac pulsation [1,2], other groups could not replicate such findings[3]. Although clinically more relevant, the effects of cardiac motion on parameters derived from the diffusion tensor have received less attention than artifacts in DW-images. This study devised a convenient technique to test the presence and a characteristic of cardiac motion induced alterations in Fractional Anisotropy (FA) and Mean Diffusivity (MD), and puts them into context with clinically relevant differences.

Method

Experimental setup: 12 gated and 12 ungated scans were acquired on 5 volunteers instructed to remain still throughout the scan-session. Both sets of acquisitions were recorded in an interleaved order (to reduce motion-bias), and the ungated TRs were individually matched to the preceding gated acquisition (to reduce T1 effects). The repetition of this investigation on 5 subjects, and the previously reported finding that scan-rescan fluctuations greatly outweigh the inter-scan, intra-subject variations[4], serve to validate and generalize the results for longitudinal studies.

Data Acquisition: Scans were acquired on a Philips Achieva 3T scanner with an 8-channel head-coil and the following parameters: b-value of 1000 s/mm^2 and 15 diffusion sensitizing directions; SENSE factor 2; partial Fourier factor 0.7; voxel dimensions 2.5x2.5x2.5mm^3; slice spacing 2.75mm; 96x96 matrix and no averaging. VCG-gating was used for triggering. Axial slice coverage ranged from the brain stem to the corpus callosum. Each slice of the gated acquisition was recorded at a different trigger-delay time providing full temporal coverage of the cardiac cycle.

Data Analysis: FSL[5] was used for brain segmentation, 2D co-registration and tensor calculations. Intra-session motion was estimated using the coregistration matrices. Motion detected in one dataset resulted in its omission from further analysis. To appreciate the maximum effect achievable, only the gated slices acquired during the still phase of the cardiac cycle were compared to corresponding non-gated slices. The necessary trigger delay-time was identified using the VCG trace. A Kolmogorov-Smirnov test was used to verify that the scan-rescan dispersions of FA and MD values did not significantly deviate from a normal distribution. Scan-rescan variance maps of MD and FA were produced for gated and ungated sets of every subject. ROI's were drawn at the core and periphery of regions experiencing intra-subject fluctuations in the absence of gating. FA and MD values over intra-subject repeats were analyzed in terms of accuracy and precision. Since the 'true' FA and MD values are unknown, the analysis of accuracy was limited to determining whether cardiac pulsation produced a significant biasing effect within each session by performing a 2-sample T-Test that does not assume equal variances. A 2-sample F-Test evaluated the significance of gating on within-session fluctuations. For the quantification of precision, the minimum change detectable with 95% confidence (MDC) was calculated from the measured standard deviation.

Results

In the scan-rescan variance-maps of different subjects only one ungated set (illustrated in the top row of Figure1) displayed a contiguous region of increased fluctuations. The apparent reduction of these fluctuations by gating, and the position of this region, suggests that the source indeed lay in cardiac pulsation. Using this information, the ROIs were defined as: the Thalamus (Thal) and the Genu & Splenium of the Corpus Callosum (GCC & SCC). Table 1 shows the group-averaged mean and MDC-values as well as the p-values corresponding to group-averaged T- and F-values for the FA- and MD-measurements of each ROI. Values of the most affected individual subject are recorded in the parenthesis. The effect of gating on accuracy and precision corresponds well to previously reported observation [2] that cardiac gating increases FA-precision and alleviates pseudo-diffusion biasing effects that lead to the overestimation of MD. The greatest improvements in precision and accuracy were found in the GCC and SCC.

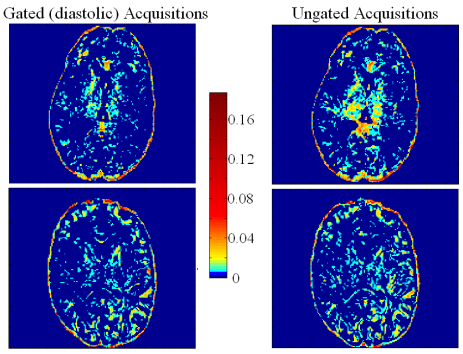

Figure 1: Intra-session FA variance-map of a scan strongly affected by cardiac pulsation (top) and a randomly selected other scan (bottom).

			GCC	SCC	Thal
FA	gated	mean	0.827 (0.883)	0.867 (0.88)	0.319 (0.386)
		MDC	0.039 (0.034)	0.028 (0.034)	0.036 (0.047)
	ungated	mean	0.819 (0.848)	0.858 (0.884)	0.309 (0.335)
		MDC	0.064 (0.124)	0.057 (0.107)	0.033 (0.08)
	T-Test p-value		**0.03** (0.088)	0.14(0.817)	0.105 **(0.0015)**
	F-Test p-value		**0,001 (<0.001)**	**0.008(<0.001)**	0.5 **(0.046)**
MD (x10^{-3}) (mm^{2}s^{-1})	gated	mean	0.745 (0.735)	0.674 (0.695)	0.643 (0.61)
		MDC	0.038 (0.03)	0.035(0.047)	0.021(0.019)
	ungated	mean	0.766 (0.818)	0.693 (0.715)	0.66 (0.644)
		MDC	0.085 (0.187)	0.053 (0.085)	0.026(0.027)
	T-Test p-value		0.07 **(0.012)**	**0.04** (0.1749)	<0.001 **(<0.001)**
	F-Test p-value		**<0.001 (<0.001)**	0.09 **(0.03)**	0.2 (0.115)

Table1: Inter-subject averaged of results of the precision analysis. The values of the most affected subject are included in parenthesis.

Discussion and Conclusions

The variations of the observed effects of cardiac gating in both this and previous studies suggest that findings must be seen as being specific to the scan-setup used. To increase confidence in the assumptions made, and ensure in the representative quality of the acquired set of scans, a larger dataset would be of benefit. The relevance of gains in precision obtained by gating may be considered with reference to a typical group investigation. The mean FA value in the Thalamus recorded in an in-house study on 9 MS-patients and 9 healthy volunteers was found to be 0.265 and 0.3435 respectively. This corresponds to a significant change of 0.0785. For the subject in this study who exhibited the largest difference between gated and ungated acquisitions, this change would be undetectable without the use of gating. The group-averaged results from this study suggest that this change would be detected whether gating was used or not. This suggests that when using the described setup in group studies of the thalamus, gating will not provide any relevant improvement in precision. However, gating should still be considered if precise individual acquisitions are required.

References

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