Do we need cardiac gating in brain-DTI at high (3T) and ultra-high (7T) field strengths?

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Introduction

Diffusion-weighted MR acquisitions (DWI) are sensitive not only to microscopic diffusion processes, but also to bulk tissue-movement such as may arise in the brain as a result of cardiac pulsation. The effect of cardiac pulsation on DWI may be reduced by synchronizing acquisitions to the cardiac cycle. However, it is not clear whether the additional time and effort required for gating allows sufficient improvements in data quality to justify its adoption as a standard practice. Recent investigations demonstrate the susceptibility of single component measurements [1], Scalar Diffusion Tensor (DT) indices [2] and tractography-results [3] to cardiac induced brain motion. Optimized gating schemes [4], as well as the retrospective omission of scans acquired during periods of increased brain movement (retrospective gating) have been suggested to minimize scan-time prolongation due to gating. A quantitative evaluation of the practical relevance of cardiac-pulsation induced errors was not possible in these studies as special DTI-sequences using the minimum number of diffusion-directions were used to reduce acquisition times. In [5], the magnitude of artifacts observed in specific anatomical ROIs when using a standard DTI sequence was estimated. Due to the low numbers of practically achievable repeats, the ephemeral nature of cardiac pulsation effects presents a limiting factor for the sensitivity and precision of such measurements. Lastly, the magnitude of cardiac-pulsation effects is predicted to increase with field strength [4]. This investigation aims to address these outstanding issues: to achieve generalisability, the upper bound of the cardiac-pulsation induced effects was estimated; to predict cardiac-pulsation effects in repeat-populations larger than can be measured, bootstrapping simulations were employed; and finally, to test the effect of field strength on cardiac pulsation effects, measurements were performed at 3T and 7T.

Method

Experimental setup: Acquisitions were confined to axial single-slice scans in order to allow for the repetition of measurements. The slice-position was chosen to include the midbrain as it not only experiences the highest levels of motion, but also as the orientations of its main fibers are perpendicular to that of the motion (thus avoiding saturation effects limiting the effect-manifestation). Two sets of Diffusion MRI-acquisitions were performed: (i) to measure the time-course of cardiac-pulsation effects, the Diffusion Coefficient along the head-feet direction (D_z) was recorded at eight 25ms intervals. (ii) 8 and 12 repeats of DTI acquisitions gated to the time-point of minimum and maximum motion were acquired in an interleaved fashion in eight and three healthy volunteers at 3T and 7T respectively.

Data Acquisition: Scans were acquired on a Philips Achieva 3T and 7T scanner with an 8- and 16-channel head-coil respectively. The following parameters were set: b-value of 1000 s/mm^2; SENSE factor 2; partial Fourier factor 0.7; voxel dimensions 2.5x2.5x2.5mm^3; 96x96 matrix and no averaging. VCG-gating was used for triggering. For the DTI-scans, the standard Philips 'no overlpus' 15 direction scheme was used with one b=0 acquisition. Padding was used to restrain head motion.

Data Analysis: FSL[6] was used for co-registration and DT-calculations. Prior to the analysis, datasets with obvious motion artifacts were omitted by visual inspection. D_z of data-sets acquired to the point of maximum and minimum motion were compared (Figure 1) to detect where the systolic window was missed. In total, two 3T and one 7T-datasets were discarded. In the remaining datasets, single measured DWI-scans were randomly selected and recombined into 1000 simulated (bootstrapped) DTI datasets. To simulate ungated and retrospective-gated cases, the probability of selecting an acquisition gated to the maximum motion was set to the percentage of the heart-beat duration taken up by the Full Duration at Half Maximum (FHDM) of the cardiac pulsation induced increase in D_z. In the ungated case these scans were included, and for the retrospectively gated case omitted. For each simulated dataset, the midbrain-voxel FAs were calculated and subsequently averaged. Figure 2 illustrates the cumulative change in midbrain-FA from a standard reference-value defined as the median FA of the simulated diastolic-gated population.

Results

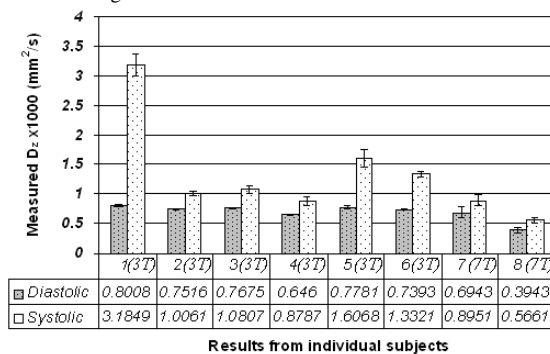|	1(3T)	2(3T)	3(3T)	4(3T)	5(3T)	6(3T)	7(7T)	8(7T)
▣ Diastolic	0.8008	0.7516	0.7675	0.646	0.7781	0.7393	0.6943	0.3943
☐ Systolic	3.1849	1.0061	1.0807	0.8787	1.6068	1.3321	0.8951	0.5661

Results from individual subjects

Figure 1: Inter-subject comparison of mean and standard deviation of repeated (8x at 3T and 12x at 7T) ADCz measurements acquired during phases of minimum and maximum motion.
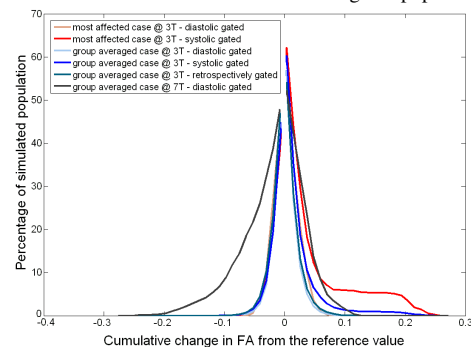

Figure 2: Cumulative histogram comparison of the maximum effects that can be expected on FA-measurements when acquisitions are not gated, to when they are gated to diastole or retrospectively at both 3T and 7T.

Cardiac pulsation was found to result in positive D_z-biasing with magnitudes varying strongly between volunteers. The effect-FHDM consistently corresponded to around 6% of the heat-beat duration. When averaged over volunteers, only moderate differences were observed between the FAs of simulated gated and ungated DT-datasets. In the most affected case (volunteer 1), FA-overestimations of up to 0.26 occurred. In approximately 6% of ungated datasets FA-values deviated by more than 0.1 from the reference value while none of the simulated diastolic-gated datasets revealed errors of this magnitude. At 7T no cardiac-pulsation effects were observed.

Discussion and Conclusions

This investigation demonstrates that cardiac pulsation can potentially cause considerable FA-errors if unaccounted for. At a group level, however, this effect diminishes. The limited beneficial effect of cardiac gating on our scanner setup may be contributable to the short time-window during which DWI-acquisitions were susceptible to cardiac pulsation (6% compared to the reported 20%). In this setup, retrospective gating is expected to offer the best compromise requiring no additional acquisition time and suffering immaterial losses in SNR. Unless the scan-rescan stability of DTI at 7T is improved, it appears to not benefit noticeably from gating.

References

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