Analysis of noise corrected diffusion decay of human brain

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Background and Purpose: Water diffusion in brain tissue is slower than for free water diffusion due to the presence of tissue microstructure. Consequently, molecular displacement is extremely sensitive to geometrical features, such as cell size and fiber orientation [1]. In white matter (WM), diffusion is faster parallel to the axons than in the perpendicular direction. In grey matter (GM), the measured anisotropy is much lower since the tissue structures are macroscopically heterogeneous. Several studies have shown that at high b-values, there is a significant deviation of the MR signal, for both GM and WM, from the basic mono-exponential model [2, 3]; however, there is no clear consensus as to whether the diffusion decay has one or more exponential contributions. Our purpose was to carefully characterize the macroscopic diffusion attenuation behavior in WM and GM over an extended range of b-values up to 10,000 s/mm^2, and to use a post-processing scheme to reduce the noise bias due to the Rician distribution of the magnitude data [4] to see if a second exponential component could be observed. It is well known that low signal to noise ratio (SNR) signals in magnitude MR images are biased to higher values by the noise.

Methods: All measurements were performed on a 1.5 T whole body clinical scanner (Symphony Quantum, Siemens Medical Systems, Germany). One healthy volunteer was recruited and scanned on 6 different days. Diffusion-weighted images were acquired for 2 diffusion sensitization directions, inferior-superior (IS) and left-right (LR), using a single-shot EPI sequence with 96 b-values (0 - 10,000 s/mm^2), TR/TE = 930/200 ms, Δ = 50 ms, matrix = 128x128, FOV = 30x30 cm^2, slice thickness = 5 mm and NEX = 6. The resulting voxel size was 2.3x2.3x5 mm^3. The slice of interest was tilted from axial to an orientation parallel to the line joining the genu and splenium of the corpus callosum. DTI images were acquired for 12 directions using b = 0 and 500 s/mm^2 (TR/TE = 4300/117 ms). The total imaging time was 9 min 18s. DTI Studio software [5] was used to obtain Fractional Anisotropy (FA) maps. The WM and GM ROIs were selected in areas of high FA (~0.8) and low FA (~0.14), respectively. Signal decay curves were noise corrected [4] and fitted using two different fitting techniques: Levenberg-Marquardt (L-M) and Non-negative Least Squares (NNLS) [6].

Results: 1) The signal decay in WM was found to be non-exponential for diffusion perpendicular to the axons (IS) (see Table 1). The effect of noise correction was insignificant in this case since the signal intensity was far above the noise floor [7] for all b-values. 2) For diffusion parallel to the axonal fibres (LR) the WM signal decayed exponentially to a constant noise floor (Fig. 1.a). 3) The signal decay in GM was exponential with a constant noise floor for both diffusion directions although the decay constant differed by about 30%. There is a non-negligible anisotropy in GM (≈ 0.14) that could be consistent with this difference between the diffusion coefficient values. The noise reduction algorithm had a significant effect on the GM decays and the WM decay for diffusion parallel to the axons (Fig. 1.b), reducing the noise floor by about a factor of 2-3.

Conclusions: Our results show that noise can have a significant effect on the diffusion decay and can easily lead to misinterpretation of the diffusion behavior for quickly decaying signals. This effect can clearly be seen in Fig. 1.b where the uncorrected decay, shown for b = 0 - 4,000 s/mm^2, appears to be bi-exponential while the noise corrected decay looks like an exponential decay. This behavior is not apparent in the results presented in the table since the full range of b-values was used in the fitting; however, when the reduced range shown in Fig. 1.b is used, the uncorrected data displays a strong second exponential component

The noise corrected signal decays presented here suggest that a second component often reported for GM could be due to the effects of noise bias (Fig. 1b). To within the limitations of the noise reduction technique employed here, our results strongly suggest that for GM and for diffusion parallel to the axonal orientation in WM the diffusion decay is exponential.

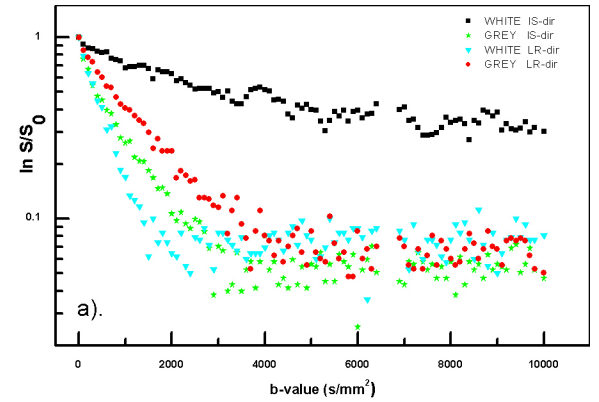

Figure 1 :

Figure 1: a) Noise-corrected diffusion decay curves for WM and GM ROIs for diffusion in the SI and LR directions. b). Diffusion decay for GM (LR direction) before and after noise reduction.

ROI (3x3 pixels)		White matter IS-dir M±SD (fraction±SD)	White matter LR-dir M±SD (fraction±SD)	Grey matter IS-dir M±SD (fraction±SD)	Grey matter LR-dir M±SD (fraction±SD)
D_1x10^{-3}(mm^2/s)	Corr	0.60±0.15 (0.46±0.07)	2.02±0.12 (0.95±0.02)	1.64±0.22 (0.84±0.03)	1.12±0.26 (0.82±0.06)
L-M	Uncorr	0.66±0.16 (0.41±0.06)	2.15±0.13 (0.87±0.01)	1.81±0.21 (0.80±0.02)	1.27±0.24 (0.75±0.04)
D_2x10^{-3}(mm^2/s)	Corr	0.05±0.02 (0.51±0.09)	0.04±0.01 (0.06±0.01)	0.07±0.05 (0.08±0.03)	0.04±0.03 (0.08±0.03)
L-M	Uncorr	0.05±0.02 (0.56±0.08)	0.002±0.001(0.13±0.01)	0.04±0.01 (0.13±0.01)	0.030±0.006(0.15±0.01)
D_1x10^{-3}(mm^2/s)	Corr	0.75±0.24 (0.37±0.09)	2.15±0.15 (0.69±0.14)	1.08±0.10 (0.10±0.07)	0.86±0.01 (0.67±0.08)
NNLS	Uncorr	0.84±0.25 (0.28±0.15)	2.40±0.18 (0.32±0.12)	1.13±0.25 (0.14±0.05)	0.90±0.18 (0.14±0.05)
D_2x10^{-3}(mm^2/s)	Corr	0.22±0.13 (0.49± 0.11)	2.06±0.07 (0.29±0.10)	1.06±0.12 (0.52±0.14)	0.83±0.10 (0.07±0.07)
NNLS	Uncorr	0.18±0.11 (0.47± 0.11)	2.08±0.07 (0.55±0.12)	1.09±0.07 (0.37±0.07)	0.88±0.05 (0.49±0.14)
Noise Floor	Corr	0.26±0.06	0.07±0.01	0.050±0.001	0.0600±0.0001
	Uncorr	0.29±0.06	0.13±0.01	0.09±0.01	0.120±0.006

Table 1: Experimental results obtained after fitting the corrected (Corr) and uncorrected (Uncorr) signal decays for the different ROIs.

References: 1). C Clark et al, Magn Reson Med, 44:852-859 (2000) ; 2). R V Mulkern et al, NMR Biomed 12:51-62 (1999); 3). T Niendorf et al, Magn Reson Med, 36 :847-857 (1996); 4). A Cardenas-Blanco et al, Proc. Intl. Soc. Magn. Reson. Med 15 (2007); 5). H Jiang et al, CMPB 81:106-116 (2001), 6) C L Lawson, R J Hanson, Solving least squares problems. Siam (1995) , 7) D K Jones, et al, MRM 52:979-993 (2004)