Effects of Motion on Clinical Diffusion Tensor Imaging

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Introduction

Diffusion Tensor Imaging (DTI) is a valuable tool in brain research and has the potential to be used clinically. However, in comparison to conventional MRI, DTI suffers from a low signal-to-noise ratio (SNR) and is highly sensitive to bulk motion of the object of interest. It is known that the gradient sampling scheme affects the precision and accuracy of a DTI experiment, due to differences in noise performance [1]. To address this issue, various studies have proposed optimized schemes, with minimum noise propagation [2,3]. Unfortunately, it is not always trivial to implement these schemes on current clinical scanners. Moreover, in a clinical setting, subject motion may have a considerable effect on the data due to the increased tendency of patients to move and the inability to restrain patients. In order to improve the quality of DTI within the constraints of clinical MRI, the reproducibility of six clinically standard available gradient sampling schemes [4] are assessed *in vivo* with and without motion correction. In addition, simulations were performed, in which motion was artificially added to the *in vivo* data.

Methods

In vivo experiments. Single-shot spin-echo echo-planar-imaging (SE-EPI) DTI experiments were conducted on six healthy volunteers (5 male, 1 female, aged 23-28 years) on a 3T Philips Achieva whole body scanner (Philips Medical Systems, Best, the Netherlands). Each subject was scanned twice with an average interval between the scan sessions of 14±8 days. The six sampling schemes, which varied in directional resolution (Ndir) and gradient amplitude (Gamp) (Table 1), were employed in random order. The sampling schemes were matched for total scan time (Tacq) by setting the number of averages (NSA) appropriately. The acquired images consisted of 52 contiguous, axial slices (SENSE-factor = 2, b-value = 800 s mm^{-2}, slice thickness = 2.5 mm, matrix size = 112 x 112, and field of view = 230 x 230 mm). Mean diffusivity (MD) and fractional anisotropy (FA) maps were calculated utilizing CATNAP [5] and the resulting images were spatially normalized using SPM2 [6]. To assess reproducibility, the intra-class correlation coefficient (ICC = $SD_{bs}^2 / (SD_{bs}^2 + SD_{ws}^2)$, where SD_{bs} and SD_{ws} represent the between-subjects and the within-subjects standard deviation [7]) was calculated voxelwise for the entire cerebrum. To assess the effect of motion correction all analyses were performed with and without co-registration of the diffusion-weighted images (FLIRT [8]).

Table 1: ***Gradient schemes with corresponding parameters***

	Low	*Low+*	*Medium*	*Medium+*	*High*	*High+*
Ndir	6	6	15	15	32	32
Gamp [mT/m]	31	43	31	43	31	43
Echo time [ms]	66	56	66	56	66	56
NSA	14	14	6	6	3	3
Tacq [min:sec]	13:04	13:04	12:56	12:56	14:01	14:01

Motion simulations. The *in vivo* data sets of a single arbitrarily chosen scan session were used to investigate the effect of motion for all six sampling schemes. Motion was simulated retrospectively by shifting and rotating the consecutive diffusion-weighted images based on a random walk model. This simulation consisted of 1000 different motion trajectories in which the direction of translation and rotation was unrestricted, but step size was fixed, so that the amount of motion agreed with values from previously obtained fMRI time series (0.5° and 1 mm for rotation and translation, respectively). The same analysis was applied to the simulated data as to the *in vivo* data for comparison.

Results and Discussion

The *medium* and *high* schemes (Table 1) were found to have similar reproducibility (Fig. 1a) both in terms of the mean ICC averaged over the full cerebrum and the spatial variance (denoted by the error bars). When co-registration was not performed, both the *low* sampling schemes displayed considerably lower ICC values and larger spatial variance, indicating lower reproducibility. Motion correction improved the reproducibility for the *low* schemes, but had a negligible effect on the *medium* and *high* schemes. Fig. 1b shows the mean estimates of FA in the frontal gray matter (GM). In regions with low anisotropy, such as the frontal GM, all sampling schemes reported similar FA when co-registration was performed, but differed when co-registration was omitted. In particular, for the *low* schemes, the mean FA values were higher when no co-registration was used, indicating that motion may introduce a positive bias for the *low* schemes. Our motion simulations also predicted that the amount of positive bias is dependent on the sampling scheme used (Fig. 2). Both the *low* sampling schemes incurred a distinct increase in FA when motion was induced. Besides the overplus variant, the *medium* and *high* schemes did not exhibit any change in FA when motion was induced, and thus appeared to be less sensitive to motion.

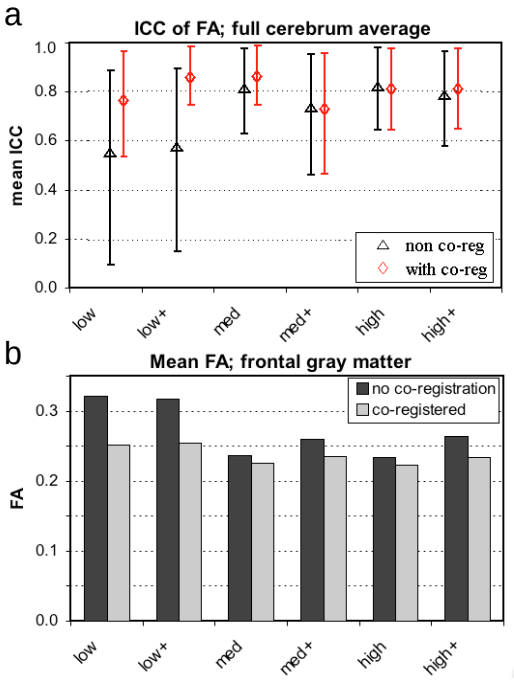

Figure 1: *The effect of motion correction. a) The ICC values averaged over the full cerebrum. b) The mean FA estimates within the frontal GM.*

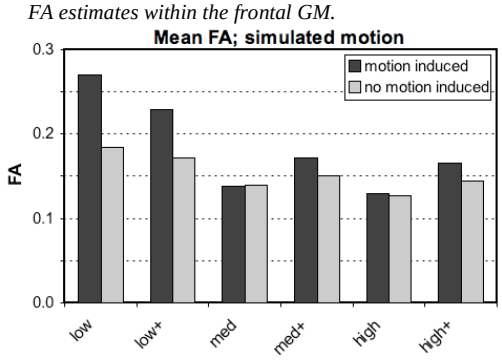

Figure 2: *The effect of simulated motion. The mean estimates of FA within the frontal GM.*

Conclusion

Our data show that, like image noise, motion effects are dependent on the sampling scheme used for the acquisition. We found that, although the *medium* and *high* sampling schemes have similar precision (reproducibility) and accuracy (bias), the *low* sampling schemes have lower reproducibility and incur positive bias for FA in the presence of motion. Co-registration improves the accuracy and precision of affected data.

References

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