White matter microstructure in brain correlates with serial reaction time motor performance: a DTI study

Cheolpyo Hong
Department of Radiological Science
Daegu Catholic University
Daegu, Republic of Korea
chong@cu.ac.kr

***Abstract*—Serial reaction time (SRT) task is used to quantitatively measure the characteristics of movement parameters and leaning capability related to motor skill learning and memory. However, no diffusion tensor imaging (DTI) study of inter-individual variation has been conducted the neural mechanisms of serial reaction time performance through changes of white matter microstructure. In this study, we attempted to identify neural correlates of individual difference for SRT task in the subcortical structures, using a DTI. According to the serial reaction time task presented on the screen, participants pressed the buttons on a response box. Each button was labeled with a number representing the finger of the right hand to be used. A 24-digit sequence of numbers indicating the presenting sequence of the task was performed. Tensor estimation methods with and without image quality control were compared using standard linear regression method and linear regression through outlier pixel rejection when corrupted pixels checking, as an image quality inspection. Binary mask from rejected bad pixels was extracted and masked fractional anisotropy (FA) values of were calculated for statistical analysis. All corrupted bad pixels were detected on the inferior portion of brain. The mean movement time is 355.27 ± 53.07 in the SRT task. Positive correlation for FA vs. individual SRT task performance capability was found in the middle region of corona radiate. Negative correlation for FA versus performance capability was detected in the middle cerebellar peduncle. High performance capability correlated with local FA values located within the most prominent projection fiber participating motor control in the subcortical structures.**

Keywords—Serial reaction time (SRT) task, Diffusion tensor imaging, Bad pixels rejection, Corona radiate

I. Introduction

Diffusion tensor imaging (DTI) noninvasively enables to assessment of neural tracts at the subcortical level and allows more specific evaluation of neurologic disease. In particular, motor performance is a critical role of human behavior [1]. Such a performance motor network can be measured by motor performance behavior task. Serial reaction time (SRT) task is used to quantitatively measure the characteristics of movement parameters and leaning capability related to motor skill learning and memory [2]. Motor network is mediated by brain [3]. White matter microstructure is strong related the motor performance [4]. However, no DTI study of inter-individual variation has been conducted the neural mechanisms of serial reaction time performance through changes of white matter microstructure.

Also, in order to achieve specific evaluation and characterization of the integrity of neural tracts by DTI, accurately and precisely estimation of DTI-derived indices, such as fractional anisotropy (FA) and mean diffusivity (MD), is an important [5]. DTI parameter value useful for assess brain function. DTI severely suffer from several artifacts, such as eddy current, patient motion, susceptibility artifacts, pulsation, and intrinsic signal-to-noise ratio [6].

Corrupted DT image by artifacts might cause DTI-derived indices over- and under- estimation [7]. Such artifacts introduce errors in tracts-specific evaluation, so that image quality control including artifacts correction has been one of key procedures in DTI data processing. Such an image quality inspection and correction scheme are not fully evaluated especially brain stem region. Methods for image quality control to detect and correct image artifacts using image co-registration have been extensively studied in DT image processing pipeline. Eddy current and mild subject motion can be correct by linear transformation of images, such as automated image registration and mutual information. Furthermore, nonlinear transformation showed the excellent artifact correction performance in a previous study. Although tensor estimation by using pixel rejection of corrupted DTI was introduced and implemented, the performance of this scheme has not yet been evaluated in clinical area.

In this study, we attempted to identify neural correlates of individual difference for SRT task in the subcortical structures using DTI after artifacts correction. Also we demonstrate the effect of image quality inspection in diffusion tensor imaging processing pipeline.

II. Subjects and Methods

A. *Image acquisitions*

Twenty healthy volunteers (13 men, mean age: 21.95 ± 1.09 years) were enrolled in this study. All subjects understood the purpose of the study and provided written, informed consent prior to participation.

The DTIs were acquired using a Synergy-L Sensitivity-Encoding (SENSE) head coil on a 1.5-T Philips Gyroscan Intera scanner. The DTI data were collected using a single shot spin echo planar imaging sequence at 1.73 mm × 1.73 mm × 2.3 mm. Sixty-seven contiguous slices (matrix = 128 × 128, field of view = 221 mm × 221 mm, repetition time/echo time = 10,726/76 ms, SENSE factor = 2, EPI factor = 67, b = 1000 mm2 s−1, NEX = 1, and thickness = 2.3 mm) were acquired for each of the 32 non-collinear diffusion-sensitizing gradients.

B. *DT image quality inspection*

Subject head motion effects and image distortions due to eddy currents were corrected by realigning each DTI volume image to a b=0 volume image using the mutual information library in DTI-Studio 3.03 (Department of Radiology, Johns Hopkins University, Baltimore, Maryland, USA). Tensor estimation methods with and without image quality inspection were compared using standard linear regression method and linear regression through outlier pixel rejection when corrupted pixels checking, as an image quality inspection. Binary mask from rejected bad pixels was extracted and masked FA values of were calculated for statistical analysis.

Values of FA derived from the DTI data were conducted to voxel based morphometric analysis. Individual B0 images were aligned to a target image provided by the SPM. Using these registration parameters, the FA images from each individual were co-registered to the target image and the group FA image was calculated.

C. Serial reaction time (SRT) task

According to the serial reaction time task presented on the screen, participants pressed the buttons on a response box. Each button was labeled with a number representing the finger of the right hand to be used. A 24-digit sequence of numbers indicating the presenting sequence of the task was as follows: 3-1-2-4-1-2-4-3-2-4-3-1-3-2- 4-1-4-2-1-3-1-4-2-3.

III. RESULTS

Results of outlier pixel rejection procedure is shown Fig. 1. Original diffusion weighted image for different orientation, theory image generated by theoretical tensor fitting value rejected binary pixels after outlier pixel rejection performed. White arrow indicates that corrupted pixels of original diffusion weighted image and those of corresponding the rejected pixels through the outlier pixel rejection procedure.

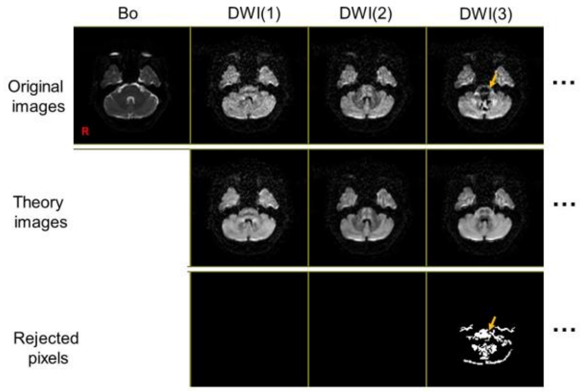

Fig. 1. Results of outlier pixel rejection procedure.

Flowchart of the FA value comparison procedures is shown in Fig. 2. In this procedure, the slice with the maximum number of rejected pixels was selected in each individual. FA images derived from SLR method and OPR method. Binary mask image generated by outlier pixel rejection performed. Resulting masked FA images after binary mask applied to the two FA images.

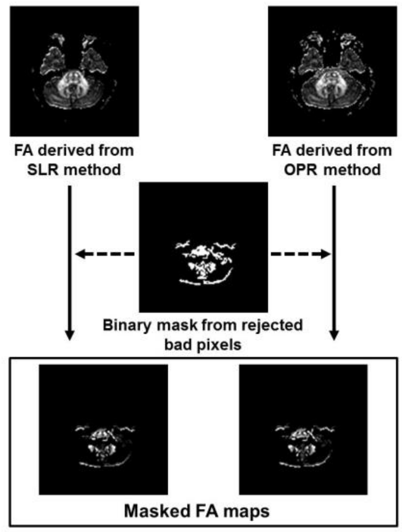

Fig. 2. Flowchart of the FA value comparison procedures

Figure 3 show the difference between the FA for slice-by-slice in the whole brain with and without corrupted pixels rejection. The differences for FA were strongly affected in near the inferior and the most superior slices along the outlier rejection procedure.

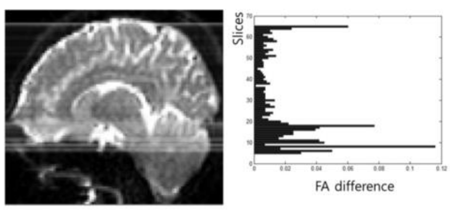

Fig. 3. Difference between the FA for slice-by-slice in the whole brain with and without corrupted pixels rejection.

Positive correlation for FA vs. individual SRT task performance capability was found in the middle region of corona radiate, shown in Fig. 4(a). Negative correlation for FA vs. performance capability was detected in the middle cerebellar peduncle, shown in Fig. 4(b). High performance capability correlated with local FA values located within the most prominent projection fiber participating motor control in the subcortical structures.

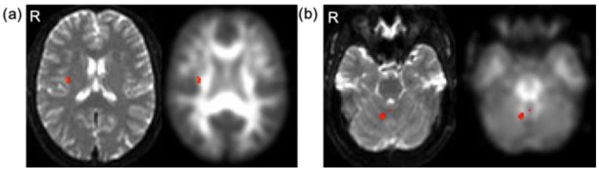

Fig. 4. Color-coded map on the averaged Bo and FA image

The mean movement time was 355.27 ± 53.07 and response accuracy was 82.45% in the SRT task.

IV. DISCUSSION

Our findings identify motor learning capability correlates with the subcortical structures. Also, we demonstrated the difference between the FA of corrected images with and without the tensor estimation through automatic outlier rejection. The differences for FA were severe in near the inferior and the most superior slices through the outlier rejection tensor estimation. These regions strongly affected by the air/tissue susceptibility artifacts. In addition, the differences for masked FA values were severe in near the brain stem and the cerebellum, inferior portion of brain. These regions strongly affected by the pulsation and the air/tissue susceptibility artifacts. Results show that FA of DTI is sensitive to of image quality inspection in processing pipeline. Moreover, the fibers extracted through the outlier rejection were differently located to the fibers without outlier rejection at the level of mid-brain region. We believe that outlier rejection can be reducing susceptibility artifacts.

REFERENCES

[1] Robertson EM. The serial reaction time task: implicit motor skill learning?. Journal of Neuroscience. 2007 Sep 19;27(38):10073-5.

[2] Knopman D, Nissen MJ. Procedural learning is impaired in Huntington's disease: Evidence from the serial reaction time task. Neuropsychologia. 1991 Jan 1;29(3):245-54.

[3] Knopman D, Nissen MJ. Procedural learning is impaired in Huntington's disease: Evidence from the serial reaction time task. Neuropsychologia. 1991 Jan 1;29(3):245-54.

[4] Kwon YH, Nam KS, Park JW. Identification of cortical activation and white matter architecture according to short-term motor learning in the human brain: functional MRI and diffusion tensor tractography study. Neuroscience Letters. 2012 Jun 27;520(1):11-5.

[5] Jiang H, Chou MC, Van Zijl P, Mori S. Outlier detection for diffusion tensor imaging by testing for ADC consistency. InProceedings of the International Society for Magnetic Resonance in Medicine 2009.

[6] Landman BA, Huang AJ, Gifford A, Vikram DS, Lim IA, Farrell JA, Bogovic JA, Hua J, Chen M, Jarso S, Smith SA. Multi-parametric neuroimaging reproducibility: a 3-T resource study. Neuroimage. 2011 Feb 14;54(4):2854-66.

[7] Li Y, Shea SM, Jiang H, Lorenz CH, Mori S. Improved, real-time artifact detection and reacquisiton for diffusion tensor imaging (DTI). InInternational Conference for Magnetic Resonance in Medicine 2010.