Investigation tissue micro-structure changes in short term neuro-plasticity with diffusion MRI

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Introduction

Characterizing structural brain plasticity with MRI and especially DTI is gaining interest in the last years (*1, 2*). The cellular and neuronal mechanism that leads to significant tissue changes that are reflected in DTI is unclear. In addition, the inherent limitations of DTI (i.e. the averaging all diffusion component in the tissue) precludes the ability to define which water component contribute to observed changes.

Alternative to DTI, models that disintegrate the diffusion MRI signal to different sources were suggested in recent years. The composite hindered and restricted model of diffusion (CHARMED) (*3*) suggests that water diffusion in brain tissue can be modeled as a summation of two processes: restricted diffusion within neural fibers (axons and dendrites) and hindered diffusion elsewhere. In the present work we have utilized CHARMED to study structural plasticity following a short term spatial memory task.

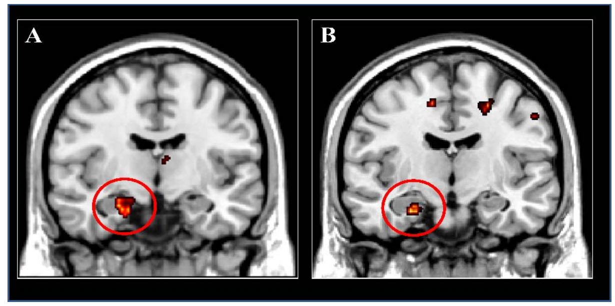

Fig. 1: (A) MD reduction in the left hippocampus following 2 hours of car-race computer game in a cohort of 17 subjects. (B) F_r increase in the left hippocampus on cohort of 10 subjects.

Methods

10 volunteers underwent two MRI scans two hours apart, separated by a spatial learning task. The learning task was based on a computer car racing game (Electronic Arts©) and included 16 laps of the same car game track, divided into 4 sessions. Their objective was to learn the track and achieve better lap times.

The DTI protocol included a series of diffusion weighted images with b value of 1,000 s/mm^2 sampled at 19 directions with additional image with b=0 s/mm^2. The image resolution was 2.1x2.1x2.1mm^3. The CHARMED protocol included 34 diffusion weighted images in different gradient directions and increasing b values (200 - 4000 s/mm^2), with additional 2 images with b=0 s/mm^2. The image resolution was 2.5x2.5x3mm^3.

DTI analysis included extraction of MD and FA maps using an in-house software.

The high b value images were corrected for motion *(4)* and analyzed according to the CHARMED framework (*3*) to extract maps of the restricted fraction (Fr) and MD of the hindered component.

The DTI were normalized to the MNI template with the following procedure: First, the pre- and post-learning task images of each subject were normalized to a mean image of these two scans. Then, all maps were normalized to the MNI coordinate system based on the FA maps. The same transformations for the DTI normalization were then applied to the CHARMED images. We performed statistical voxel-based analysis separately for all maps, by using a paired t-test. All coregistration, normalization and statistical analyses were done using SPM2 (UCL, London, UK).

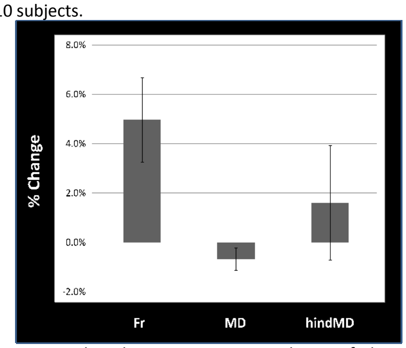

Fig. 2: The Change in F_r, MD and MD of the hindered component following 2 hours of spatial navigation game on cohort of 10 subjects. Note that ADC decrease in diminished when analyzing only the hindered compartment.

Results:

In a previous spatial navigation study in humans *(5)* it was found that short-term memory (2 hours) leads to MD decrease in the hippocampus (2.5 ± 0.6%, fig. 1a) as well as a few other brain regions. This effect however was small and necessitated a large experimental group (>20) to reach a sufficient statistical significance. Here we found similar MD decrease in the same regions (anterior left hippocampus) yet for the small cohort used here the result was non-significant (MD decrease of -0.7%).

In the same region, for the same small cohort of subjects, a significant increase in the fraction of the restricted diffusion component (extracted by CHARMED) was found (5 ± 1.7%, P=0.0013, fig. 1b). Concomitantly the MD of the hindered component did not changed significantly between the 2 scans (fig. 2).

A significant increase in the fraction of restricted diffusion component was also found in the posterior left hippocampus and parahippocampus, the insula and the cingulate gyrus (fig. 3) Similar regions were found in the previous study with larger cohort, suggesting that the effect of this task on restricted diffusion is much more pronounced.

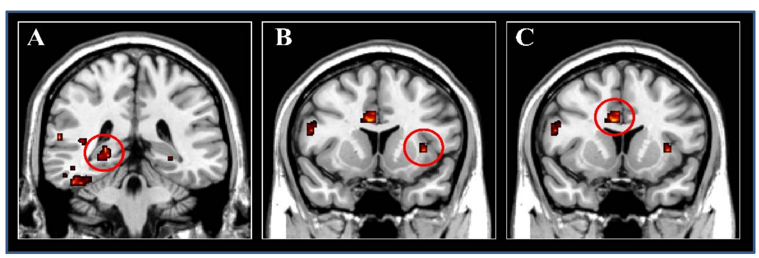

Fig. 3: Additional regions that showed F_r increase following 2-hours of car raising game including (A) the parahippocampus; (B) Insula and (C) Cingulate cortex.

Discussion

In the current CHARMED study we found that this decrease stems from increase in the proportion of restricted diffusion (believe to occur in intra-cellular space). The restricted component in CHARMED refers to diffusion within cylindrical components of neural tissue (axons, dendrites and glial processes). Therefore, although the physical meaning of this feature is straightforward in white matter, this study shows that it is also meaningful in gray matter and may represent a means to study the micron-scale networks of neurons and glia.

References:

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