The impact of white matter growth on the maturation of information processing and reaction time

N. C. Scantlebury[1], C. Rockel[1], W. Gaetz[2], N. Law[1], and D. Mabbott[1]
[1]Program in Neuroscience and Mental Health, The Hospital for Sick Children, Toronto, Ontario, Canada, [2]Biomagnetic Imaging Laboratory, Children's Hospital of Philadelphia, Philadelphia, PA

Introduction and Purpose: White matter's role in supporting neuro-transmission is well known. However, knowledge about the impact of white matter on the development of neural signaling and subsequent information processing is only now emerging. Reaction time tasks have frequently been used as a measure of information processing speed. Fundamentally, reaction time to a cue reflects the time required for neural information to travel from a point of sensory input to a point of motor or sensory output, and is dependent upon the speed at which the information is transmitted through neural circuitry. Reaction time in response to a visual cue, for instance, may be modulated by, among other things, the efficiency of signal transmission through white matter tracts required for (i) visual input - such as the optic radiations (OR), (ii) information processing - such as the inferior fronto-occipital fasciculus (IFOF; Figure 1) and inferior longitudinal fasciculus (ILF), and (iii) motor output - such as the cortico-spinal tracts (CST). While considerable inter-individual variation has been reported for reaction time tasks, the physiological and neurobiological factors contributing to the observed variation remain poorly characterized. Magnetoencephalography (MEG) and diffusion tensor imaging (DTI) have been used in concert to delineate white matter tracts associated with specific neuronal activations. To test the contributions of white matter on reaction time in children, we used the latency between a visual cue and a motor response to measure reaction time, MEG to delineate the associated cortical activation and DTI to delineate relevant white matter pathways.

Subjects and Methods: Thirty-three healthy, right- handed children (19 males) ranging in age from 4.93 to 17.44 years (mean age = 9.21 years $\pm$ 2.9) participated in the study. First, MEG data were acquired: Bi-polar EMG electrodes were placed at the left and right First Dorsal Interosseous (FDI) muscles. Subjects moved right and left index fingers separately, following a visual target. Transient movements were performed once every 4s (on average) for a total of 100 movements/side. ERB was used to localize the cortical responses known to accompany transient finger movement. Second, diffusion data were acquired with a GE LX 1.5T MRI scanner using a single shot spin echo EPI DTI sequence (15 – 25 directions, b=1000s/mm^2, TE/TR=84.7/10,000 ms, 42 contiguous axial slices, 2-3 mm isotropic, 128 x 128 matrix, FOV = 24cm, rbw = 125 kHz, NEX = 1). MEG activations marked on the T1 anatomical scan were non-linearly registered with the DTI sequence and used as seeds from which to delineate the CST via the posterior arm of the interior capsule. Anatomical landmarks were employed to delineate all other tracts. The lateral geniculate nucleus was used as a seed to delineate the OR via the calcarine fissure (CF). The CF was used as a seed to delineate both the IFOF and the ILF via the external capsule and superior frontal gyrus, respectively. All delineated tracts were used as regions of interests from which to extract measures of white matter integrity {fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD) and radial diffusivity (RD)}. Correlation analyses were performed to identify contributions of white matter development and age on reaction time.

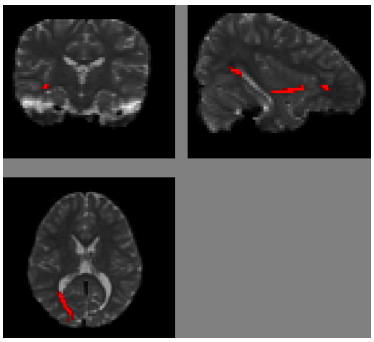

Figure 1. Tractography results depicting the IFOF (red) in 3 orthogonal planes.

Results: Increasing age predicted decreasing reaction time for finger movements in both left and right hands (Table 1). Age also predicted MD and AD of the IFOF in the right hemisphere, as well as MD and RD of the CST bilaterally. FA and RD of the IFOF in the left hemisphere predicted reaction time for both hands. MD and AD of the IFOF in the right hemisphere predicted right finger reaction time. Left finger reaction time was predicted by MD and RD of the CST in the right hemisphere. Finally, MD of the CST in the right hemisphere predicted reaction time of the right finger. No correlation between age and measures of integrity in the OR or ILF was detected.

Conclusions: Here, we evaluated the contributions of age and white matter in modulating reaction time. Developmental changes in white matter integrity were apparent only in the IFOF and CST of this healthy cohort. This finding is not surprising considering that white matter matures at different rates, and the IFOF and CST run anterior to the OR and ILF. The different location of these tracts may account for variation in age-related changes. Consistent with the literature, we found that age predicted reaction time. However, a novel finding was that increased white matter organization of the IFOF in children also predicted decreases in reaction time. These findings implicate the white matter integrity of the IFOF as an important player in reaction time. Furthermore, increased integrity of the CST predicted decreased reaction time. In conclusion, this study presents evidence that white matter growth plays a significant role in modulating information processing speed. Age-related changes in white matter organization are likely involved in increasing the efficiency of signal transmission. Ultimately, these data will help to anticipate how brain maturation rates will affect behavior in the developing paediatric population.

	Age	Left finger reaction time	Right finger reaction time
Age	-	-0.548**	-0.473**
Left finger reaction time	-0.548**	-	-0.913**
Right finger reaction time	-0.473**	-0.913**	-
FA of IFOF (left hem)	0.200	-0.504**	-0.423**
RD of IFOF (left hem)	-0.191	0.410**	0.407**
MD of IFOF (right hem)	-0.471**	0.389*	0.421**
AD of IFOF (right hem)	-0.403**	0.343*	0.422**
MD of CST (left hem)	-0.621**	0.190	0.130
RD of CST (left hem)	-0.577**	0.339*	0.289
MD of CST (right hem)	-0.621**	0.450**	0.416**
RD of CST (right hem)	-0.483**	0.404**	0.333*

Table 1. Correlations among age and reaction time.
* $p < 0.05$, ** $p < 0.01$