Investigation of cerebellar microstructure with two-compartment Spherical Mean Technique

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Introduction

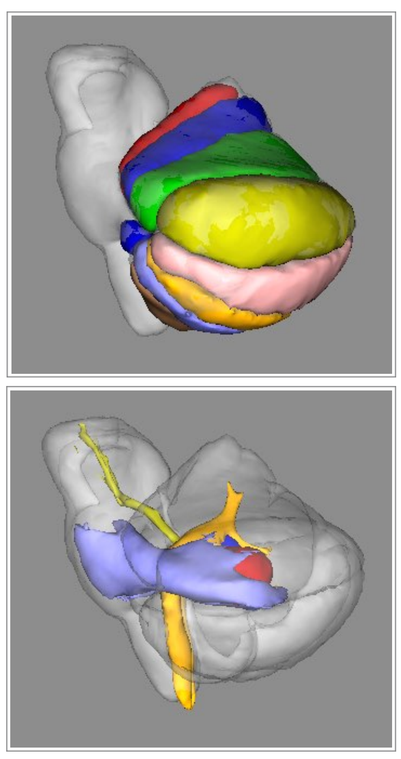
Diffusion-weighted MRI (DW-MRI) is a valid tool for *in vivo* investigation of neural tissue microstructure. Over the years a lot of attention has been dedicated to study the cerebrum. However, more recently, attention has also turned onto the cerebellum because of new evidences of its key role in complex functions and pathology. Its unique compact neural architecture can be probed with DW-MRI.

The most widely used DW-MRI signal model is the diffusion tensor (DT), which has proven to be sensitive but not specific to microstructure and inadequate, for example, in regions of complex fibres architecture. To overcome DT limitations, new techniques, models and metrics have been recently proposed and applied to study the brain benefitting also from the development of fast diffusion sequences. Amongst these innovative techniques, the spherical mean technique (SMT) makes use of the invariance property of the spherical mean of the diffusion signal with respect to the fibre orientation distribution (FOD): therefore, it is possible to estimate parameters of complex diffusion signal models directly from the data, making no a priori assumptions about the underlying FOD.

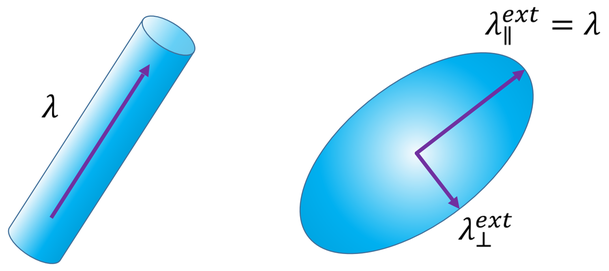
The aim of the present work is to characterize cerebellar microstructure using the SMT in its recently proposed two-compartment version, considering a validated anatomical parcellation.

Methods

High-quality images of 76 subjects from the Human Connectome Project were analysed, 100 Subjects Data Release with minimal pre-processing pipeline, structural and diffusion sessions. High-resolution structural images were registered to diffusion data. The cerebellum was isolated and registered to the SUIT standard space with SPM and the SUIT toolbox. The SUIT probabilistic anatomical cerebellar atlas and the probabilistic atlas of cerebellar peduncles were considered for this study.



The DT model and the two-compartment SMT were applied to diffusion data in the cerebellum. The two-compartment model assumes brain tissue to be divided into an extra-neurite compartment and an intra-neurite domain: the signal originating from the diffusion motion of water molecules is expressed as the sum of two separate contributions, where the former is described with a tensor and the latter, highly anisotropic, is modelled as a zero-radius cylinder (stick model).

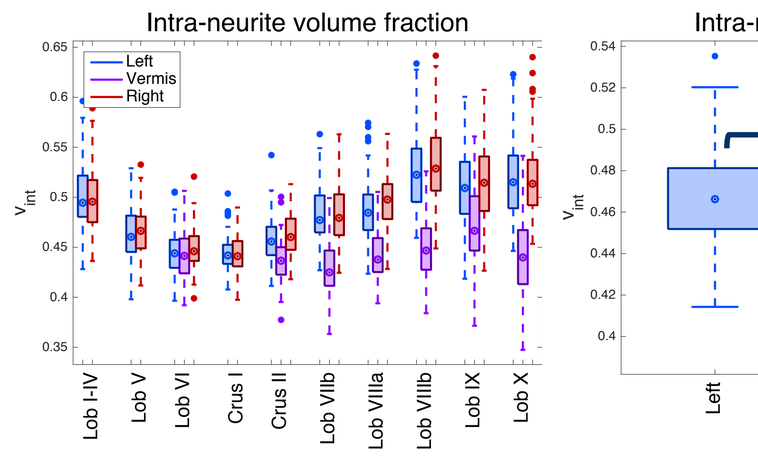


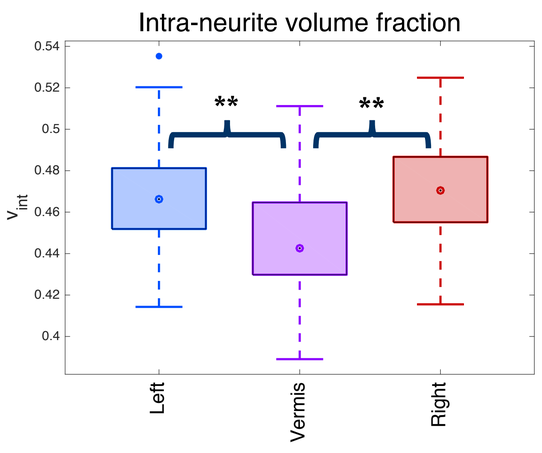
Intra-neurite Extra-neurite

Results

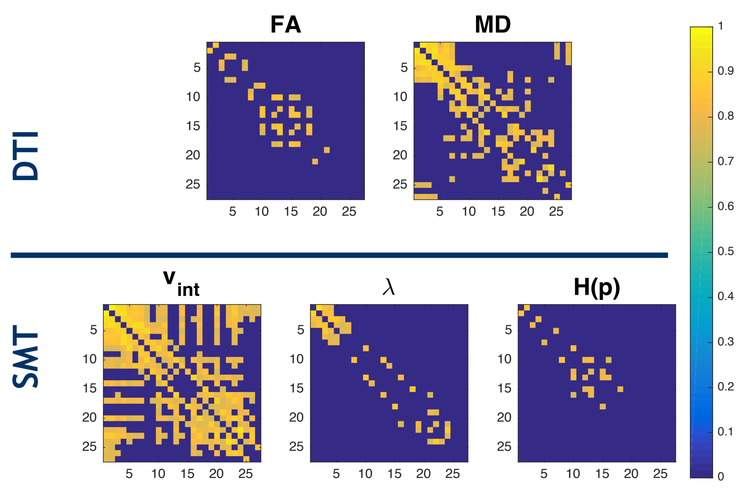
Region-specific average values of SMT/DTI metrics were obtained within cerebellar cortical regions (GM), cerebellar peduncles (WM) and deep cerebellar nuclei (Deep GM) derived from SUIT. Here differences of intra-neurite volume fraction between cerebellar lobules are reported (left).

DW-MRI images analysis reflects results reported by studies of phylogenesis and cytoarchitecture: from a phylogenetic point of view, the vermis is known to be more ancient than the cerebellar hemispheres and therefore its neurons exhibit a minor arborization; moreover, studies of the cerebellar cytoarchitecture reported larger somas diameters and packing density of Purkinje, Golgi and Granule cells in the vermis with respect to the hemispheres. In line with these results vermis lobules exhibit an inferior v_{int} (right).





Diffusion microstructure metrics can also be adopted to find consistent microstructural features between regions across subjects.



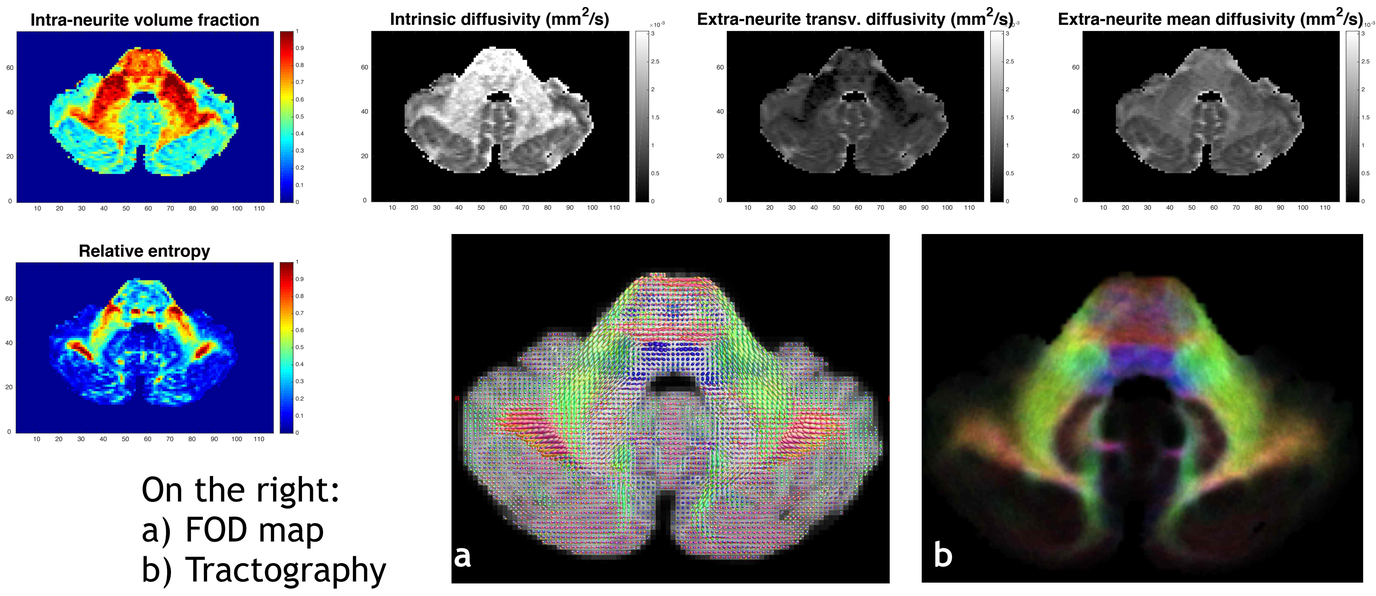
Here, cross-correlation matrices of DTI and SMT indexes for 27 cerebellar lobules across subjects are reported: higher correlation values represent consistently varying microstructural patterns across subjects.

Conclusions

We investigated for the first time the unique **cerebellar microstructure** with a recent, advanced diffusion method: the **two-compartment SMT**. SMT-derived microstructural parameters are **not confounded by underlying FOD**.

Microstructural metrics can give a deeper insight into cerebellar features with respect to DT metrics. DT metrics are sensitive to microstructural changes but not specific. Microstructural metrics are more specific and may possibly provide a more direct **link with cytoarchitecture**.

Microstructural features



On the right:
a) FOD map
b) Tractography

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