Three-dimensional maximum probabilistic cerebellar atlas of young children

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Target Audience Researchers performing structural and functional MRI of the cerebellum.

Purpose To construct an atlas of the cerebellum in a stereotactic space which can be used in future research to understand the functional organization, involvement of cortico-cerebellar loops, and to serve as a template for accurate analysis of young children data.

Introduction Recent advances in structural MRI methods have improved the anatomical detail visible on MR brain images. Brain atlases constructed from single subjects are conservative and do not represent the variability of underlying structures. Unlike single brain atlases, probabilistic anatomical atlases represent the average anatomy of specific populations. In order to assess cerebellar structural volumetric changes in young children, in this study we constructed a probabilistic atlas of cerebellar parcellations using the asymmetric template of the National Institutes of Health Pediatric Database (NIHPD) [1] for children between 7.5-13.5 years of age. The cerebellar lobules were classified macroscopically for medial, mid and lateral sections. An age-appropriate maximum probability map was developed for 40 cerebellar structures, 20 per hemisphere.

Methods High-resolution anatomical T1-weighted three dimensional (3D) structural images were acquired using a magnetization prepared rapid gradient echo (MPRAGE) sequence (TR = 2300 ms, TE = 3.93 ms, TI = 1100 ms, 160 slices, flip angle = 12 degrees, $1.3 \times 1.0 \times 1.0$ mm^3, 6.03 minutes) for 18 healthy children who were recruited as controls for studies on fetal alcohol spectrum disorders [4], mean age 11.8 ± 1.2 years (range 9-13years, 6 male), on a 3T Allegra (Siemens, Erlangen, Germany) MRI scanner. The images were reoriented along the anterior posterior commisure (AC-PC) line horizontally and in the mid sagittal plane. For manual segmentation, images were resampled to isotropic 1 mm^3 voxels using BrainVoyager. The lobules were manually traced using Multitracer [2] software by a neuroanatomist (CW). The tracings were performed in the sagittal plane using markings placed in the axial and coronal views to guide boundary determination. Boundaries were drawn on 4 times magnification to allow sub-voxel precision and reliable tracing of small-scale features. In this study, vermis was considered as a part of the medial structures. The vertical subdivisions in the posterior view (Figure 3b) subdivide the cerebellar hemisphere into medial, middle (mid) and lateral regions. The anterior lobe consisting of lobules I to V was not subdivided. Lobule I-V has only medial and mid sections. Lobe VI, CrusI, CrusII, lobules VII and VIII comprise medial, mid and lateral sections. Lobe IX is represented as the PUNs and TONs, clinically known as pyramid, uvule and nodulus. Lobe X is the flocculus (FLOs). Each cerebellar cortical label includes some white matter due to the fine branching structure of the cerebellar white matter which is difficult to exclude. This was done in a consistent manner for all structures and all subjects. The region names and their respective color codes are shown in Figure 2 and three-dimensional views of the lobules for different views are shown in Figure 3b. Ten subjects were randomly selected and traced again at a later stage to assess intra-rater reliability; intra-class correlation coefficient is 0.96.

The tracings were converted into individual discrete labels representing the different lobules of the cerebellum using in-house scripts written in Matlab. All the brains were spatially normalized to the NIHPD asymmetric template using linear and non-linear discrete cosine transformation using SPM5. The corresponding priors of GM, WM and CSF were used in the stages of segmentation [3]. The transformations were applied to the labelled structures of each subject and were resampled into the template space. The volumes of all the structures in native space were compared with volumes after spatial normalization to the age-appropriate atlas using correlation analyses in order to validate whether relative magnitudes were preserved. A maximum probabilistic atlas was constructed by assigning to each voxel in the template space a label corresponding to the region to which it belonged in most subjects together with a probability equal to the percentage of subjects in whom it belonged to said region. At the boundary of two structures, the mode of each voxel for the respective label was determined across all subjects in order to assign a unique label to each structure. A probability threshold of 0.2 was applied to reduce outliers.
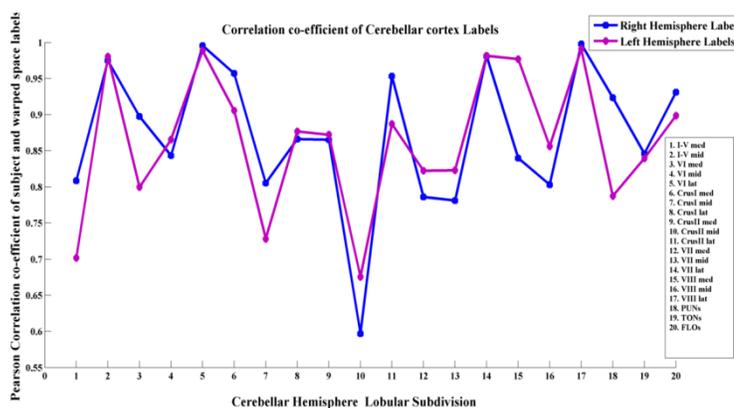

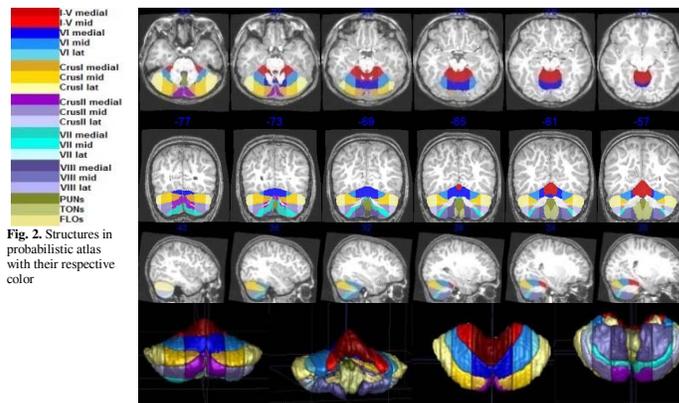Fig 1.Pearson correlation coefficient between the label volumes in subject space and normalised space

Fig. 2. Structures in probabilistic atlas with their respective color

Posterior view   Anterior view   Superior view   Inferior view

Fig. 3a. Maximum probabilistic atlas superimposed on the subject in atlas space (Top) axial (Middle) coronal (Bottom) sagittal

Fig. 3b. Maximum probabilistic cerebellar atlas in three-dimensional (3D) space

Results A majority voting rule was used for label propagation and construction of the maximum probability map. Figure. 1 shows good correlation between volumes from manual tracing and volumes in normalized template space. For most structures correlations are of the order of 0.8 or higher, except for left medial I-V, left mid crusI, and left and right mid crusII. There was significant variability in these structures that is attributed to inaccuracy in the subdivision into medial, mid and lateral sections. Visual inspection of the lobes superimposed on a structural image yields a good alignment as shown in Figure 3a.

Conclusions We have constructed a probabilistic cerebellar atlas for children in the NIHPD asymmetric template using manually traced images of 18 healthy controls. We have demonstrated good agreement between the volumes of manual and warped regions and good correspondenc of the atlas with structural images.

References
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