Deformation based morphometry of brain structure in children with difficulties in mathematics

Z. Han[1,2], L. Fuchs[3], N. Davis[4], C. J. Cannistraci[2], A. W. Anderson[2], J. C. Gore[2], and B. M. Dawant[1]

[1]Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN, United States, [2]Vanderbilt University Institute of Imaging Science, Nashville, TN, United States, [3]Department of Special Education, Vanderbilt University, Nashville, TN, United States, [4]Kennedy Center for Research on Human Development, Vanderbilt University, Nashville, TN, United States

Introduction

Epidemiological studies report that about 5-9% of children have a deficit in mathematical reasoning, which are manifested as learning disabilities or difficulties in developing competencies in math. Modern neuroimaging has confirmed that a reproducible set of parietal, prefrontal and cingulate areas are systematically activated when subjects are asked to perform a calculation task [1, 2]. Although functional neuroimaging has been used to study mathematical disabilities, few attempts have been made to document structural or morphological features in subjects with mathematical difficulties. Voxel-based morphometry studies on adolescent children with very low birth weight [3] and in children with developmental dyscalculia [4] show that areas in the left parietal lobe and a frontoparietal network may be involved in the neural basis of mathematical processing. Molko et al [5] investigated the intraparietal sulcus shape in people with developmental dyscalculia associated with Turner's Syndrome. However, to the best of our knowledge, no previous studies have attempted to use deformation-based morphometry (DBM) to investigate the existence of structural anomalies in children with poor mathematical skills.

Methods

Twenty third-grade children with math difficulties (8.8±0.1 years old, 12 males and 8 females) and twenty age and gender matched controls (8.8±0.2 years old, 12 males and 8 females) participated in this study. Participants' performances on the calculation subtest of the Wide Range Achievement Test (WRAT-A) were used to separate children into low and high math groups. The math difficulty (MD) group had scores below the 20^{th} percentile and children in this group had no other disabilities or mental deficiencies. Children in the normal control (NC) group had WRAT-A scores above the 50^{th} percentile. Participants with scores between the 20^{th} and 50^{th} percentile were not analyzed for the present study. The anatomical images were acquired with a 3T Philips Achieva MR scanner with matrix size of 256 x 256 x 170 and isotropic voxels of $1mm^3$. First, an atlas with average intensity and shape for all the 40 MRI images was built using the average atlas method proposed by Guimond et al [6]. This is an iterative process in which images are co-registered with a non-rigid registration algorithm. Here we have used the Adaptive Basis registration algorithm we have previously developed [7]. The magnitudes of all the inverse deformation fields from the atlas to each individual within the two groups [8] were then averaged. Two-sample *t*-tests were subsequently performed to assess whether and where the average deformation fields differed between the groups. Voxels that had an uncorrected p value of <0.005 and were part of a spatially contiguous cluster size of 70 voxels or greater were considered to be significantly different between groups [4, 9]. The center of each clustered ROI was mapped into MNI (Montreal Neurological Institute) space using SPM (Statistical Parametric Mapping) and then transformed into Talairach space using the new ICBM2TAL tool [10]. Localization of Talairach coordinates was performed by Talairach Daemon [11] and FSL atlas tools [12].

Results

Figure 1 shows the effect of two different initial references (top row) on the population atlases (bottom row). As shown, the final result is independent of the choice of the initial reference. Figure 2 shows the color-coded mean magnitudes of the deformation fields for the NC group (top panel) and MD group (bottom panel) overlaid on the atlas. Higher values in these maps indicate regions of greater morphological variance within a group. Regions with statistical differences are summarized in Table 1. As shown, the major anatomical differences between the MD and NC groups are located in the right frontal lobe, bilateral parietal lobe, right cerebellum, left occipital lobe and the conjunction of left occipital and temporal lobes.

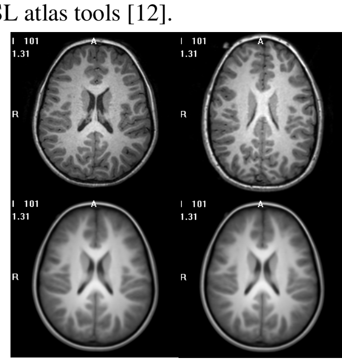

Fig. 1: Two different initial scans (top) and their corresponding atlases (bottom).

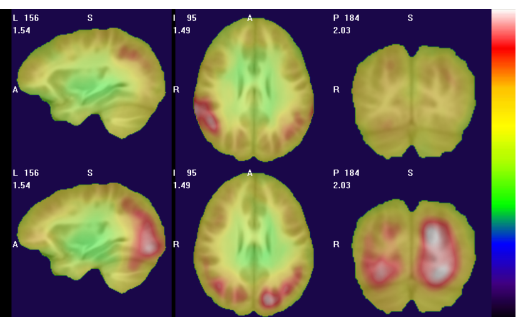

Fig. 2: The mean of magnitude of deformation fields for NC (top) and MD (bottom) groups, showing the group differences. The color map ranges from 0 (black) to 10 (white) mm.

Conclusion

In this study, DBM was applied to high resolution MRI images of children with math difficulties and normal controls. This is the first study using DBM to report group differences in structure. The results showed increased structural variance in key brain regions in MD children that may explain the functional differences seen in such subjects. For example, group differences were found in both inferior parietal lobes (BA 40). This area is bounded by the intraparietal sulcus which has been implicated repeatedly in mathematical functioning. In addition, differences were found in the right middle frontal gyrus (BA 9). This area is also known as the dorsolateral prefrontal cortex and is a part of a frontoparietal network believed to be the neural basis of impaired calculation skills. Lastly, group differences occurred in the left fusiform gyrus, an area critical to word/number recognition.

Anatomical regions	Size (mm^3)	mean P-value	Talairach coordinates
Right frontal lobe, middle frontal gyrus, (BA 6,9)	2640	0.003	40, 8, 49
Left inferior parietal lobule, and left superior temporal gyrus (BA40,42)	91	0.004	-65, -33, 21
Right inferior parietal lobule, supramarginal gyrus(BA40)	521	0.001	67, -45, 32
Right cerebellum, anterior lobe	853	0.002	6, -45, -15
Left temporal/occipital lobe, fusiform gyrus (BA 37)	656	0.003	-39, -62, -8
Left occipital lobe, middle occipital gyrus, lingual gyrus, sub-gyral (BA17,18,19)	3509	0.002	-24, -78, 2

Table 1: Statistical differences in structures between MD and NC groups

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