Shape Analysis on Subcortical Structures with its Application in Children with Autism

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Introduction

Template-based shape analysis has been widely used to assess structural shape abnormalities (volume loss and its location) in a variety of neurodegenerative and neuropsychiatric diseases. Thus far, most existing morphometric shape analysis has largely focused on a single structure, such as the hippocampus, or thalamus. Nevertheless, there is considerable morphological variation in multiple structures in neural circuits across disease population. The assessment of the degree and pattern of multiple structural shapes is necessary to optimally distinguish subjects with early forms of various neuropsychiatric diseases. We introduce an automatic shape analysis procedure through large deformation diffeomorphic metric mapping (LDDMM) that generates subcortical template, segments the structures from raw MR images, quantifies the shape variation of each individual subject relative to the template, as well as makes statistical inference on covariance of the shape variations of multiple subcortical structures [1].

Methods

A Bayesian framework under the LDDMM setting was used to estimate average diffeomorphic deformation of subcortical structures among a population and thus generate subcortical template shapes representing the population (bottom panel in Fig 1). For each individual subject, volume-based probabilistic segmentation was first used to label subcortical structures in the raw MRI scan. The subcortical template shape was then injected into the subcortical parcellations generated from the volume-based segmentation to smooth the structural boundary and correct topology via LDDMM (second and third panels in Fig 1). The statistical analysis was performed on random field representation of the template surface momentum maps that encode the shape variation of subcortical structure targets of each individual subject relative to the template. The momentum maps have the optimum property that they are supported only on the boundary of the subcortical structures with the direction normal to the subcortical nuclei boundary thereby reducing the dimension of shape variation significantly. A two-level statistical model was built on these momentum maps to assess their covariance among the subcortical structures via Laplace-Beltrami (LB) basis functions [1, 2].

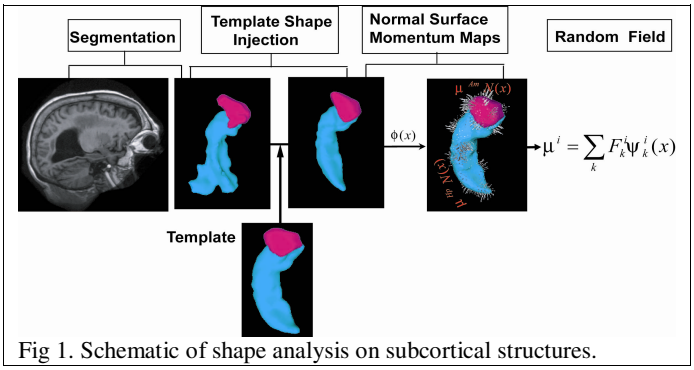

Fig 1. Schematic of shape analysis on subcortical structures.

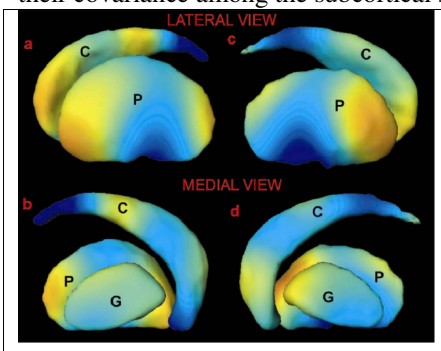

Fig 2. Left and right columns respectively illustrate the shape difference in the left and right basal ganglia in the medial and lateral views. Color encodes the local volume ratio of the typically developing group to the Autism group in the logarithmic scale and indicates the strength of the shape alteration in Autism. Warm color denotes the regions that are compressed in the boys with Autism when compared with the typically developing boys, while cool color depicts the regions that are expanded in the boys with Autism relative to the typically developing boys. Key: C --- caudate, P --- putamen, G --- globus pallidus.

Results and Conclusions

We applied the shape analysis for examining abnormalities of the basal ganglia shapes associated with effects of Autism in MR images of 38 typically-developing children and 35 children with Autism. The template of the basal ganglia was first created using our probabilistic diffeomorphic template generation approach [2] based on 35 typically-developing children. Shape variations of each structure relative to the template were found via the LDDMM-surface mapping and modeled as a random field using LB basis functions in the template coordinates. Linear regression of LB coefficients was used to examine group differences in shapes of the basal ganglia. Children with Autism showed no difference in the volumes of any structure in the basal ganglia. LDDMM revealed remarkable differences in basal ganglia shapes (Fig 2).Volume compression was seen bilaterally in the dorsal caudate head and anterior putamen and globus pallidus as well as in the posterior extreme of the left putamen. Volume expansion was seen elsewhere. The multiple shape differences found in children with Autism suggests that the disorder may not be associated with abnormalities in one specific neural circuit. Rather, it appears the disorder involves abnormalities in parallel circuits with the orbitofrontal cortex, the frontal eye field (FEF), pre-SMA, SMA, and primary motor regions. Such abnormalities in circuits are critical for motor, social, and communication impairments.

References

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