CAT - A Computational Anatomy Toolbox for the Analysis of Structural MRI Data

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INTRODUCTION

The most popular method in computational anatomy is voxel-based morphometry (VBM). This approach provides the voxel-wise estimation of the local amount or volume of a specific tissue compartment, such as gray matter (GM) or white matter (WM) and enables a completely automatic analysis across the entire brain. Another method that is closely linked to VBM is deformation-based morphometry (DBM) that relies on the analysis of deformations that are necessary to spatially register an image to a template. Furthermore, the deformations of the spatial registration can be also applied to transform labels or regions of interest (ROI) that are given in the template space to individual subject space. This method is known as region-based morphometry and allows the estimate the overall value of gray matter inside these pre-defined regions. Finally, surface-based morphometry (SBM) permits new forms of analyses, such as gyrification indices that measure surface complexity in 3D or cortical thickness.

We have extended our toolbox for voxel-based morphometry to enable the fully automatic analysis using all of these techniques. In order to demonstrate the variety of potential analyses we applied our novel CAT12 toolbox (http://www.neuro.uni-jena.de/cat) to a sample of Alzheimer's Disease (AD) patients and healthy control subjects.

METHODS

Subjects

For illustrative analyses we randomly selected the first 25 AD patients (mean age 75.97±7.1 years; mean MMSE 23.48±2.35) and 25 healthy control subjects (mean age 77.96±6.41 years; mean MMSE 28.75±1.48) from the ADNI database (http://adni.loni.usc.edu) for our analysis.

Voxel-based morphometry

In addition to our previous adaptive MAP approach for partial volume segmentation we used an approach that allows for the adaptation of local intensity changes in order to deal with varying tissue contrast (Dahnke et al. 2012a).

Deformation-based morphometry

DBM is based on the analysis of the deformations that are necessary in order to non-rigidly deform a brain to match it to another brain. The deformations now reveal information about the type and localization of the structural differences between the two brains and can be used for subsequent analysis. Here we analyzed the Jacobian determinant that allows a direct estimation of the percentage change in volume in each voxel (Gaser et al. 1999).

Region-based morphometry

We used maximum probability tissue labels derived from the Neuromorphometric atlas (provided by Neuromorphometrics, Inc. (http://Neuromorphometrics.com) to estimate the sum of local gray matter inside the defined ROI's. The anatomical atlas - which is defined in template space - was transformed to native subject space using the inverse non-linear deformations needed to spatially normalize images to template space.

Surface-based morphometry

We used a fully automated method that allows for measurement of cortical thickness and reconstructions of the central surface in one step (Dahnke et al. 2012b). In order to repair topological defects we applied a method that relies on spherical harmonics (Yotter et al. 2011a) and reparameterized the cortical surface mesh using an algorithm that reduces area distortion (Yotter et al. 2011b).

Statistical analysis

We used threshold-free cluster enhancement (TFCE) for a combined analysis about height and size of the effects and applied an FWE corrected threshold of p<0.001.

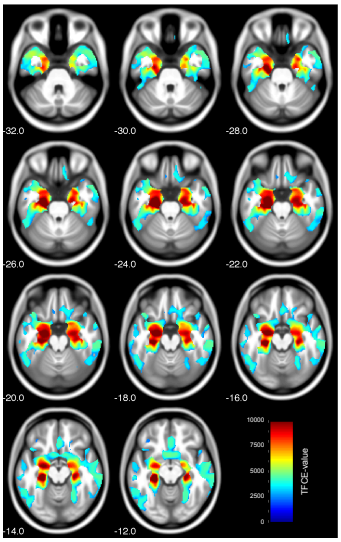

Fig. 1 Voxel-based analysis of local gray matter
Lower gray matter volume in Alzheimer's Disease patients compared to healthy control subjects (p<0.001, TFCE, FWE-corrected)

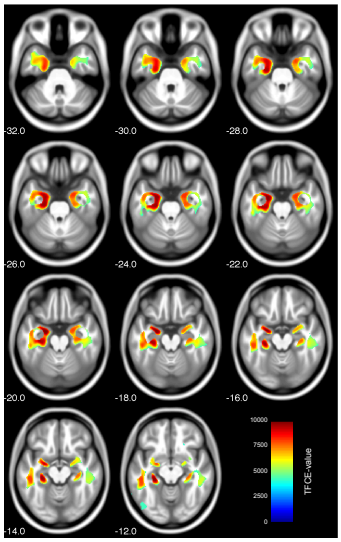

Fig. 2 Deformation-based analysis of local Jacobian Determinant
Lower volume in Alzheimer's Disease patients compared to healthy control subjects (p<0.001, TFCE, FWE-corrected)

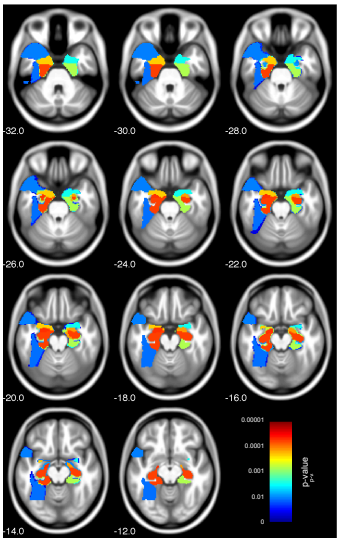

Fig. 3 ROI-based analysis of regional gray matter
Lower volume in Alzheimer's Disease patients compared to healthy control subjects (p<0.05, Holmes-corrected)

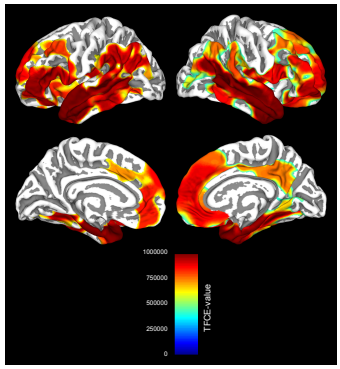

Fig. 4 Surface-based analysis of local cortical thickness
Lower cortical thickness in Alzheimer's Disease patients compared to healthy control subjects (p<0.001, TFCE, FWE-corrected)

RESULTS

The most pronounced atrophy in the patients were found bilaterally in the hippocampus, in the amygdala, in the parahippocampal gyrus, and in the right middle temporal gyrus across all methods (Fig. 1-4). Furthermore, there were large atrophy clusters found with VBM, DBM, and SBM in temporal and frontal regions.

CONCLUSIONS

We have extended our widely used VBM toolbox to ease the process of computational anatomy. The implemented methods allow various insights into brain structure ranging from local and regional measures to properties of the cortical surface.

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