Shaping up in structural neuroimaging

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Structural neuroimaging studies provide insight into development and diseases of the human brain.

Historically, neuroimaging research has focussed on the volume or surface area of the brain and its components.

Now, it is becoming clear that shape is also important [1, 2].

We have benchmarked and expanded one of the most promising shape analysis techniques in structural neuroimaging.

Global shape: global importance

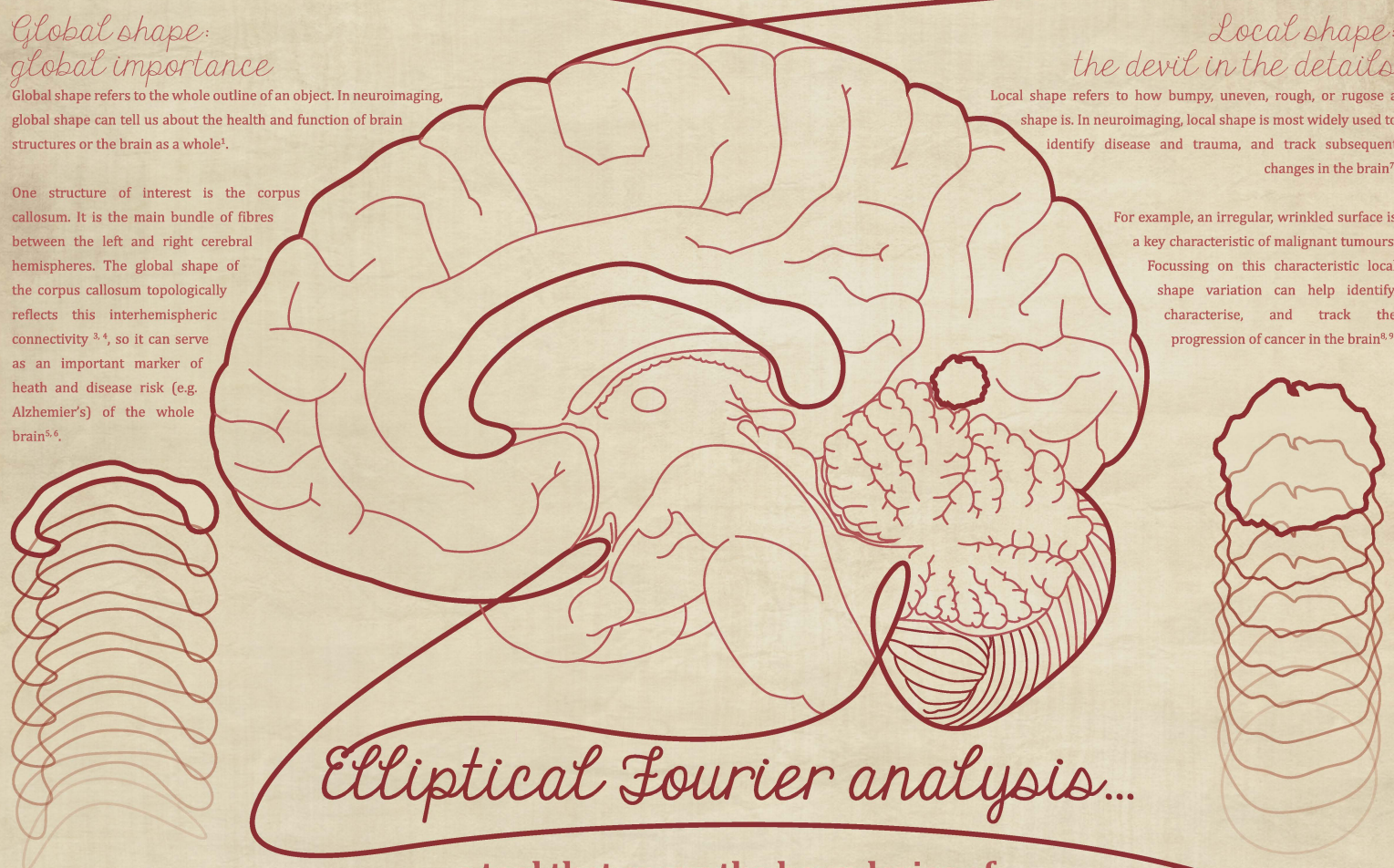
Global shape refers to the whole outline of an object. In neuroimaging, global shape can tell us about the health and function of brain structures or the brain as a whole[1].

One structure of interest is the corpus callosum. It is the main bundle of fibres between the left and right cerebral hemispheres. The global shape of the corpus callosum topologically reflects this interhemispheric connectivity [3, 4], so it can serve as an important marker of heath and disease risk (e.g. Alzhemier's) of the whole brain[5, 6].

Local shape: the devil in the details

Local shape refers to how bumpy, uneven, rough, or rugose a shape is. In neuroimaging, local shape is most widely used to identify disease and trauma, and track subsequent changes in the brain[7].

For example, an irregular, wrinkled surface is a key characteristic of malignant tumours. Focussing on this characteristic local shape variation can help identify, characterise, and track the progression of cancer in the brain[8, 9].



Elliptical Fourier analysis...

... a tool that spans the boundaries of mathematics, biological phylogenetics, neuroimaging and health.

Elliptical Fourier (eFourier) is a technique which deconstructs shape into a series of overlapping trigonometric harmonics (n harmonics for each of the x [An, Bn] and y [Cn, Dn], $(\frac{A_n^2+B_n^2+C_n^2+D_n^2}{2})^{10}$. Though most extensively used for exploring plant and animal morphology in biology, eFourier (and the three-dimensional expansion, spherical harmonic analysis or SPHARM) is gaining traction as a valuable tool for exploring global shape in neuroimaging[11].

eFourier: Benchmarking the big picture

Using 200 simulated corpus callosum-like shapes, and 168 real corpus callosum tracings from healthy community-living adults, we systematically benchmarked the performance of the eFourier technique for global shape analysis. **We found it to be reliable, computationally inexpensive, and straightforward to interpret.**

eFourier: Extension into the local domain

We established a new measure of local shape complexity based on a step already used in global eFourier shape analysis, the harmonic power requirement (HPR). We simulated 12,558 shapes with precisely known local shape properties. **We showed HPR to be a sensitive, robust measure of local complexity that provides complementary information to fractal dimensionality, which is currently the most widely applied measure of local shape information in neuroimaging.**

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References

1. Gerig G, Styner M, Shenton ME, Lieberman JA. Shape versus size: Improved understanding of the morphology of brain structures. Medical Image Computing and Computer-Assisted Intervention–MICCAI 2001; 2001: Springer; 24-32. | 2. Small CG. The statistical theory of shape: Springer Science & Business Media, 2012. | 3.Zaidel E, Iacoboni M. The parallel brain: the cognitive neuroscience of the corpus callosum: MIT press, 2003. | 4. Aboitiz F, Scheibel AB, Zaidel E. Morphometry of the Sylvian fissure and the corpus callosum, with emphasis on sex differences. Brain 1992;115:1521-1541. | 5. Barkovich AJ, Norman D. Anomalies of the corpus callosum: correlation with further anomalies of the brain. American journal of neuroradiology 1988;9:493-501. | 6. Teipel SJ, Bayer W, Alexander GE, et al. Progression of corpus callosum atrophy in Alzheimer disease. Archives of Neurology 2002;59:243-248. | 7. Di Ieva A, Esteban FJ, Grizzi F, Klonowski W, Martín-Landrove M. Fractals in the neurosciences, part II: clinical applications and future perspectives. The Neuroscientist 2015;21:30-43. | 8. Baish JW, Jain RK. Fractals and cancer. Cancer Res 2000;60:3683-3688. | 9. Di Ieva A. Angioarchitectural morphometrics of brain tumors: are there any potential histopathological biomarkers? Microvasc Res 2010;80:522-533. | 10. Kuhl FP, Giardina CR. Elliptic Fourier Features of a Closed Contour. Computer Graphics and Image Processing 1982;18:236-258. 11. Ferrario VF, Sforza C, Serrao G, Frattini T, DEL FAVERO C. Shape of the Human Corpus Callosum: Elliptic Fourier Analysis on Midsagittal Magnetic Resonance Scans. Investigative radiology 1994;29:677-681.