Statistical Analysis of Surface Roughness via Local Area Maps:

Application to the Cingulate in Healthy and Schizophrenia Subjects

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Introduction

Quantifying the organization of the innermost layer of the cortical mantle, i.e., the roughness of the gray-white matter interface at the level of magnetic resonance (MR) scans, could offer a new approach for testing the hypothesis that aberrations in neurodevelopment are involved in the pathogenesis of schizophrenia [1,2]. We propose a new method for assessing the regularity of the cortical mantle. The roughness of a surface is quantified using the local area map which is a measure of surface area per unit volume. Statistical properties of the local area maps can be used to determine whether one surface, or group of surfaces, is rougher than the other.

Methods

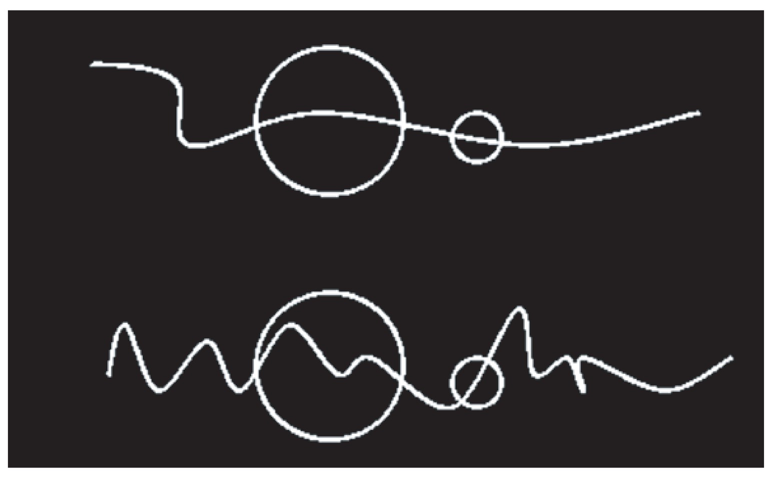

Figure 1: 1-D illustration of local area map

Figure 1 illustrates the intuitive notion that a rough surface should have a larger area within a given region of space than a smooth or flat one. The length of the curve that is inside the big circle is larger for the bottom curve than for the top curve, indicating that the bottom curve is has more roughness. However, the concept of the roughness of a surface is dependent on a choice of scale. At a finer scale, represented by small circles in the figure, both curves look equally smooth reflecting the fact that the lengths of the intersections of the two curves with the smaller circles are approximately the same. If the surface has many bumps inside a ball then the local area will be larger than if the surface was flat inside that ball. However, if the surface has just one bump in the ball then the local area can be much smaller than if the surface was flat. For this reason, we also consider a related measure of bumpiness we call the magnitude of the relative local area, which is large when the local area of the surface is either significantly larger or smaller than the local area of a plane. Given a scale parameter, σ, at each point on the surface we can compute the area of the intersection of the surface with a three-dimensional ball of radius σ. Surface roughness is quantified by convolving the area element of the surface with a 3D gaussian kernel, whose standard deviation σ, is interpreted as the scale parameter. The resulting function on the surface is referred to as the local area map. In this study, gray-white surfaces of the cingulate cortex were reconstructed from MR images at a resolution of $0.5mm^3$ that were collected from 54 schizophrenia subjects and 68 healthy controls, group matched for age, gender and parental socioeconomic status [3,4].

Results

At each scale, the median and standard deviation of the local area histogram for each surface was computed. A one-sided rank-sum test was performed to determine whether the computed statistic (median or standard deviation) was larger for the group of schizophrenia subjects than for the healthy subjects group. A similar analysis for the magnitude of the relative local area was also performed. The table shows *p*-values for one sided rank-sum tests on median and standard deviation of the local area, and the median of the magnitude of the relative local area, computed at the finest scale of σ=0.5 mm in the left, right, anterior and posterior cingulate regions. Figure 3 shows local area maps at three scales (0.5, 1.5, and 5 mm) for the right posterior cingulate surface of one control and one schizophrenic subject. These results indicate a statistically significant group difference for the right anterior and posterior cingulate. The results suggest that at the scale σ=0.5 mm, the right cingulate is rougher for the group with schizophrenia than for the control group.

	LA	RA	LP	RP
median (rel. loc. area)	0.15	0.025*	0.07	0.02
median (loc. area)	0.25	0.035*	0.11	0.025*
std. dev (loc. area)	0.45	0.02*	0.1	0.03*

Figure 2 demonstrates that the local area statistics can distinguish rougher surfaces from smoother ones. Six types of synthetic surfaces were obtained by adding randomly chosen bumps to the surface of one quarter of a donut labeled I, II, III, IV, V and VI, with 100 surfaces for each type. All surfaces had 200 large bumps and an additional 0, 100, 200, 300, 400, 500 small bumps for each type.

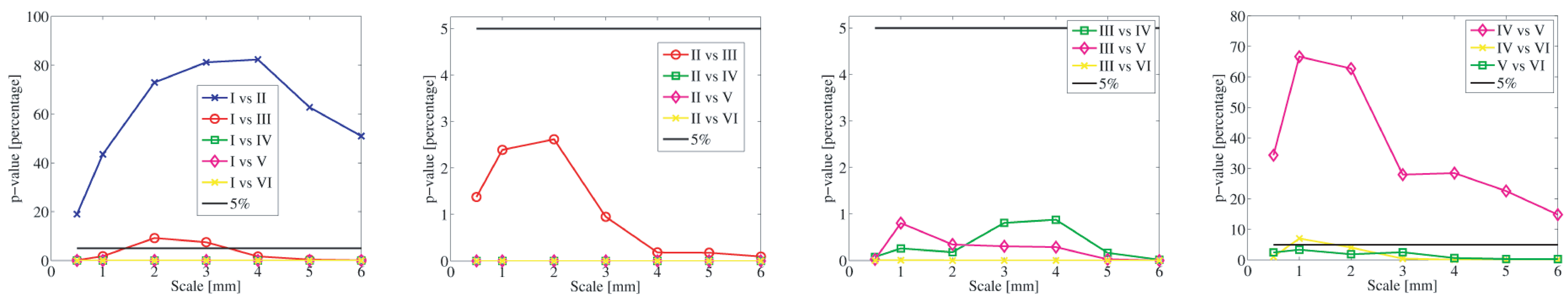

Figure 2: *p*-values vs local area scale for one sided rank-sum tests to determine if median of the median local area is larger for groups of synthetic surfaces with a larger number of small bumps.

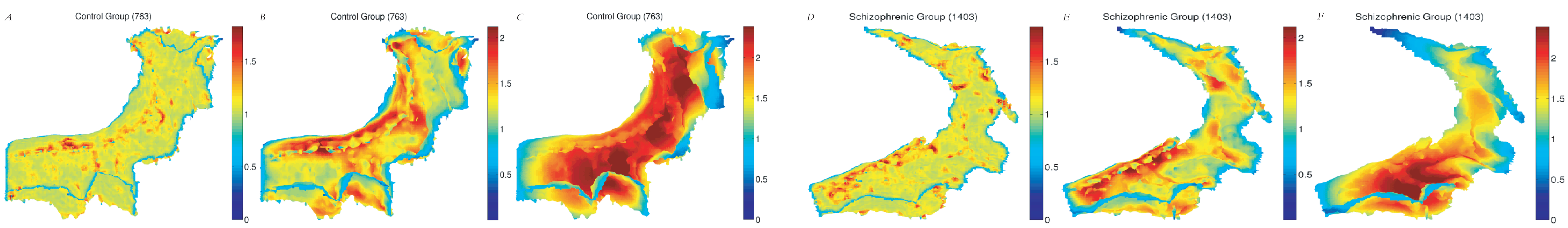

Figure 3: Local area maps computed at different scales for two subjects, one control, (A-C) and one schizophrenic (D-F). For each set, from left to right, the scales are 0.5, 1.5, and 5 mm.

Discussion

A series of simulations were used to demonstrate the sensitivity of the method to biologically relevant degrees of variation in roughness of the gray-white matter interface. The results suggest that the roughness of the interface between gray and white matter within both anterior and posterior right cingulate gyrus was significantly greater in the schizophrenia subjects than in the healthy controls. To the extent that an increase in roughness of the gray-white matter interface suggests disorganization of the innermost cortical layer, these results are consistent with the hypothesis that schizophrenia is characterized by a defect in cortical development.

References:
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[4] Wang L., et al, 2007, Abnormalities of Cingulate Gyrus Neuroanatomy in Schizophrenia *Schizophrenia Research* (In Print)

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