Holes, objects, and the left hemisphere

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The human visual system is remarkably efficient at extracting useful information, especially in detecting objects in our environment. Many models have been developed over the years to account for this amazing ability, most following the sensible hierarchy of detecting features first and then integrating them to build objects (1, 2). A notable exception to this general scheme is the theory of topological perception proposed by Lin Chen (3). During the last 25 years, Lin Chen and colleagues have argued for the importance of extracting global topological properties as primitives in object perception (4). The emphasis on global properties in perception is not new [e.g., Gestalt theory of perception (5)], but the topological perception theory specifically defines the global properties as topological invariants. In addition, this theory states that the primitives of visual form perception are geometric invariants at different levels of structural stability under transformations. Thus, a more stable property would be more primitive and more important to extract early in the process. Topological properties are the most stable in relation to other geometrical properties such as projective, affine, and Euclidean properties. In a recent issue of PNAS, Lin Chen and colleagues (6) reported the intriguing discovery that the human visual system's sensitivity to topological properties is superior in the left hemisphere, at least for right-handers (Fig. 1).

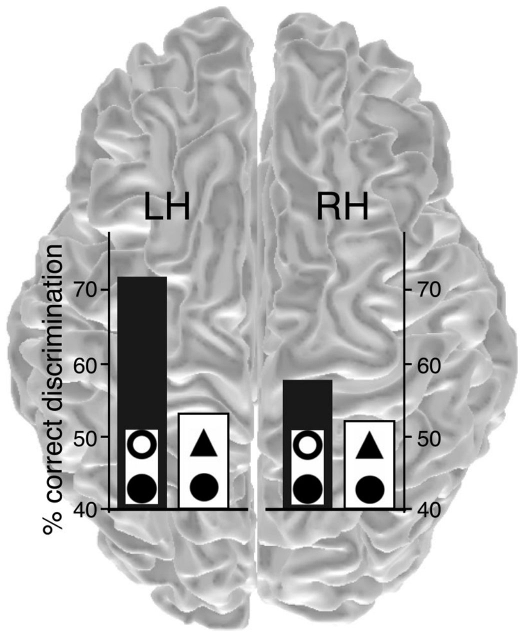

Fig. 1. Schematic depiction of the left hemisphere's superiority in topological discrimination. A pair of shapes was briefly presented in either the right or the left visual field, projecting initially to the left or right hemispheres (LH or RH), respectively. Observers were asked to respond to whether the two shapes were the same or different. Although the triangle may appear more different from the disk than the ring does, human observers are more sensitive to the difference between the disk and the ring, which are topologically different, but are less sensitive to the difference between the triangle and the disk, which are topologically equivalent (3). Now, the authors show that the ability to discriminate topological differences is more superior in the left hemisphere than in the right hemisphere, as indicated by the bar plots showing the percent correct discrimination (adapted from figure 1G of ref. 6).

Functional lateralization in the human brain is the rule rather than the exception, most notably for high-level cognitive functions such as language (7). Important lateralization also exists for visual information processing. Extrastriate visual cortex contains well known category-selective areas, some of which have consistent biases to one hemisphere or the other. For example, the fusiform face area (FFA) is much more robust in the right hemisphere than in the left hemisphere (8). However, in terms of the neural encoding of basic visual shapes and spatial information, the picture is less clear. Studies over the last few decades have characterized the relative specialization of the two visual half brains along a number of dimensions. Lateralization could be based on stimulus properties and task demands such as the spatial frequency content of the stimuli, extraction of global vs. local properties, etc. (see ref. 9 for a review). The most notable theory is the one developed by Kosslyn *et al*. (10, 11), which proposes that the left hemisphere is more adept at processing categorical spatial relationships, whereas the right hemisphere is more efficient at processing coordinate spatial relationships. As reviewed by Wang *et al.* (6), there are inconsistencies in the existing literature on hemispheric lateralization of visual functions, and they suggested that the topological account provides a unified solution to characterization of the hemispheric asymmetry in visual shape perception. Although a claim of a unified model requires more theoretical as well as empirical support, the topological model does provide a coherent account and precise predictions about the functional lateralization of visual shape perception. In contrast, what defines a categorical spatial relationship rather than a coordinate one is often a matter of subjectivity and is context-dependent. Thus, a key advantage of the topological account of the left hemisphere's superiority lies in its precise formulation and specific predictions, although in some instances, the topological account of the hemispheric asymmetry and the categorical vs. coordinate relationship model converge.

At the foundation of the argument that the perception of topological properties has the potential to serve as a unifying principle for visual functional lateralization is the belief that topological properties are in fact primitive properties of object perception. The idea that global properties can (and should) serve as primitives in object perception may seem counterintuitive. After all, neurophysiological evidence predominantly points to the initial level of feature analysis before global shape repre-

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sentation is achieved. However, as emphasized in Chen's review article (4), the key to understanding these issues lies in the understanding of "transformational invariants." Consider, for example, a bird flying from a tree branch. The actual shape of the bird will change dramatically, whereas the oneness of the bird does not. Similarly, even for nondynamic objects, the relationship between the viewer and the object determines the exact geometry of the visual image, yet we are capable of perceiving it as the same object whether viewing it from the left or right. Chen (4) suggests that during possible transformations, the most stable form properties are described by topological invariance—one shape will not break into two, nor will any new holes be created. Because topological properties are the most stable properties under transformation, it makes sense that in normal visual perception, the extraction of topological properties serves as the starting point of object perception [i.e., as primitives (12)]. Indeed, the ultimate reason for the left hemisphere's advantage could be in the properties' importance in defining objects. Although the topological theory primarily targets the initial steps in visual form perception, its emphasis on property stability under transformation shares the spirit, in an abstract sense, with modern probabilistic theories of vision such as the Bayesian decision theory (13, 14) and the empirical ranking theory (15). Both have their early roots, with the Gestalt and Gibsonian tradition (5, 16) for the topological theory and Helmholtz for the statistical inference theories (17). The topological perception theory attempts to highlight stability amidst large variability in visual input, whereas statistical inference approaches explain unambiguous perception from uncertain retinal images.

The extraction of topological properties serves as the starting point of object perception.

Topological precedence is clearly evident in the results shown in the current study, because responses to topological differences were both faster and more accurate than control conditions. Indeed, the topological advantage over discrimination of other properties is robust for both the left and right visual field presentations. The findings reported here reveal that on top of the general topological precedence, the left hemisphere had an additional advantage for discriminating topological properties compared with the right hemisphere for right-handers (Fig. 1). In other words, it is not the case that the right hemisphere is better at processing other discrimination types than topological perception. Topological perception has an advantage in both hemispheres, but more so in the left hemisphere. This pattern of results, although consistent with an overall superiority for topological properties, does present a confounding issue of task difficulty in that the left hemisphere advantage is associated with easier tasks. The authors point to earlier lateralization studies showing that the task difficulty was not the reason for the left hemisphere's advantage for categorical discrimination (11). The argument against task difficulty would be stronger if task difficulties were equated in the current study.

With functional magnetic resonance imaging (fMRI) measures, Wang *et al.* (6) also searched for the potential neural correlates of enhanced topological sensitivity. Two sets of fMRI experiments converge to a region in the left temporal lobe, a site somewhat anterior to category-selective visual cortical sites. This is different from other recent imaging studies aimed at revealing the neural correlates of categorical vs. coordinate perception, which showed perceptual categorical lateralization in the left angular gyrus (18) and imagery tasks of categorical or coordinate nature lateralized to the left and right superior parietal lobule, respectively (19). So why does the left temporal site have enhanced sensitivity for topological discrimination? One wonders whether this site serves as a bridge to a more conceptual representation of visual input. Indeed, an important function of the study of Wang *et al.* is to shed new light on relatively "old" yet unresolved issues and to stimulate more research examining the nature of visual information processing, especially with unconventional ideas.

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