Topological Structure in Visual Perception

Abstract. *Three experiments on tachistoscopic perception of visual stimuli demonstrate that the visual system is sensitive to global topological properties. The results indicate that extraction of global topological properties is a basic factor in perceptual organization.*

A primitive and general function of the visual system may be the perception of global topological properties (*1*). Consider the relationship of figure to background. When a perceptual stimulus is presented under impoverished visual conditions, figure and ground achieve "some measure of differentiation" (*2*), although the detailed structure of the stimulus remains vague and amorphous. That the precise shape could not be perceived means that this kind of perceiving does not depend on the details of the shape. In other words, a stimulus was separated into different global wholes (a figure and a background), dependent only on global properties. These global properties can be described mathematically as topological properties, such as connectivity. When we speak of "objects" in a picture, we usually imply that they are connected (*3*).

If topological properties play a role in visual perception, we should predict some experimental phenomena that are not necessarily consistent with our everyday perceptual experiences, but with topology. In the following experiments, a tachistoscope controlled the duration of visual information processing and this topological structure was revealed.

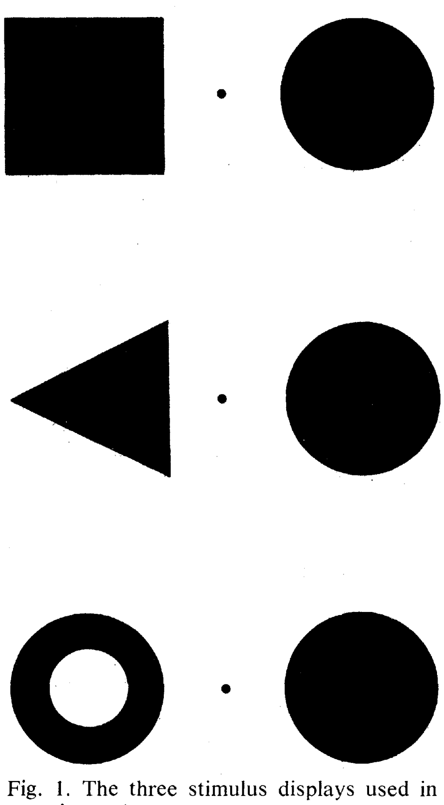

Fig. 1. The three stimulus displays used in experiment 1.

From our intuitive experience, circles, triangles, and squares are seen to be far different figures; from the viewpoint of topology, however, they are equivalent. Circles and rings are topologically different. Thus, we might predict that the discrimination between rings and circles might be possible even when the discrimination of circles from triangles or squares is not. To test this prediction, six naïve subjects were shown the stimulus patterns illustrated in Fig. 1 (*4*). Subjects looked at the fixation point on a preexposure field and pressed a button to receive a 5-msec presentation of a field containing one of the three stimuli, followed by the immediate reappearance of the preexposure field. Both the order of the three stimuli and whether the circle was on the left or the right were random. For each presentation, the subject was asked to report whether the two figures in one display were the same or different. The intensity of the preexposure field was fixed, and the intensity of illumination of the target field was adjusted to keep an overall probability of reporting "different" of 50 percent. (In fact, the displays were always different.)

The visual system was more sensitive to the topological distinction between a connected component with a hole (a ring) and one with no hole. On the average, the stimulus which contained a circle and a ring was reported as "different" on 64.5 percent of the presentations; the stimulus which contained a circle and a square, on 43.5 percent; and the stimulus which contained a circle and a triangle, on 38.5 percent. The accuracy with the stimulus containing a ring was significantly better than one containing either a square or a triangle [$t(5) = 8.78$ and $t(5) = 6.12$, respectively, $P < .01$]. For the topologically equivalent figures (triangle and square), the difference did not reach significance [$t(5) = 1.37$, $P > .20$].

Zeeman predicted that cataract patients, who could not tell triangles from circles just after being operated on, ought to be able to detect homology invariance, for example, to detect holes or to distinguish a doughnut from a bun (*5*). Because such patients are rare, this experiment has not been tried yet. Now, under conditions of tachistoscopic presentation, his hypothesis about the topological structure in visual perception has been supported.

Some of the configural superiority effects reported (*6*) may be due to topological properties, such as connectedness or closedness. Indeed, connectedness and closedness have been considered important structural components of perceptual representation (*7*). A second experiment compared the sensitivity of visual systems to a single line segment with that to a line segment that was a part of a connected and simple closed figure (Fig. 2).

To avoid the bias of a subject's focusing on the position where the target line would appear, the target line appeared on either the left or the right of the exposure field. The context was designed to be symmetrical so that by itself it did not provide any clue as to which side a target line was located in. However, it formed a connected and closed figure in conjunction with either target line (*8*).

In a procedure similar to the first experiment, four subjects reported which side the target line was on for each presentation. The duration of exposure

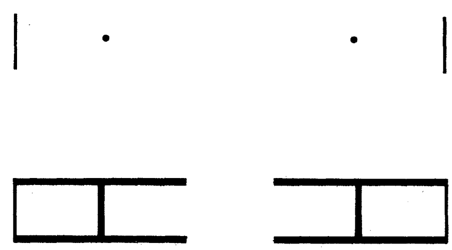

Fig. 2. The four stimulus displays used in experiment 2.

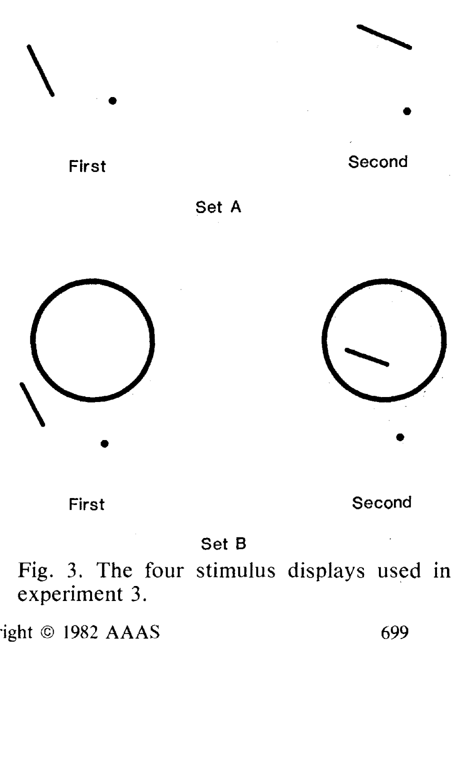

Fig. 3. The four stimulus displays used in experiment 3.

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was 50 msec, and the intensity of the illumination of the exposure field was adjusted to keep an overall mean average accuracy of about 70 percent. The order of presenting the stimuli was random.

On the average, the target line was reported correctly on 86 percent of the presentations when it was a part of a connected and closed whole. But, when it was presented alone, only 55 percent were reported correctly [$t(3) = 6.85$, $P < .01$]. This result indicates clearly that the connected and closed structure can facilitate the detection of the target line that is a part of it.

Another distinction made in topology is whether in a plane a line is contained in a closed curve or not. If the idea about the topological structure of form vision is right, this kind of topological property should also be able to facilitate the identification of target lines.

In a third experiment, two pairs of stimuli (Fig. 3) were used. The two target lines contained in set A differed both in position and slope. Set B contained both the same target lines and an additional circle in each stimulus, so that one target line was in the circle and the other one outside. Because the additional circle was located in the same position, this context gave no clue about which of the two target lines was presented (*9*).

The procedure was similar to that of experiments 1 and 2, except that the two stimuli of each pair were presented successively on the same trial in random order. The eight subjects were simply required to indicate which target line was first and which second. With set A, mean accuracy was 59.2 percent and with set B, 79.1 percent [$t(7) = 7.17$, $P < .001$].

The data of these three experiments are difficult to interpret in terms of traditional feature detector models or spatial frequency filter models (*10*). But it is direct, natural, and consistent to explain all of them in terms of early detection of global topological properties, defined in terms of the invariant properties under topological transformations. These experimental facts are therefore relevant to Gibson's theory of invariance detection.

From the perspective of the general theory of computation, the nature of topological invariants makes their computation difficult (*11*). How should we treat the contradiction of these experimental results with the computational account of perception? The results are consistent with Gibson's insight that "The perceptual system simply extracts the invariants from the flowing array; it resonates to the invariant structure or is attuned to it" (*12*), although now we do not know how this resonance to topological invariants is generated. This kind of question lies at the core of issues in perception (*13*).

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References and Notes

1. With the aid of the mathematics of tolerance spaces [E. C. Zeeman, *Topology of 3-Manifolds*, K. Fort, Ed. (Prentice-Hall, Englewood Cliffs, N.J., 1962), p. 240], we can describe global properties on a discrete set. Thus, numerous facts of visual perceptual organization, for example, the Gestalt laws of proximity and similarity, may be described mathematically by the global topological (or tolerance) properties (L. Chen, paper presented at the 4th Biophysical Academic Conference of China, Beijing, May 1979; paper presented at the 14th Annual Mathematical Psychology Meeting, Santa Barbara, August 1981). Some of the configural superiority effects (*6*) and global precedence [D. Navon, *Cognit. Psychol.* **9**, 353 (1977)] can also be considered as evidence that visual systems are superior at perceiving topological properties before perceiving more detailed geometrical properties of stimuli.
2. J. H. Flavell and J. Draguns, *Psychol. Bull.* **54**, 197 (1957).
3. A. Rosenfeld, in *Advances in Computers*, M. C. Yovits, Ed. (Academic Press, New York, 1979), vol. 18, p. 40.
4. The diameter of the circle is 32 mm; the length of the short side of the isosceles triangle is 32 mm, and the long sides of it, 42 mm; the length of one side of the square is 32 mm; the outer diameter of the ring is the same as that of the circle, and that of the inner circle, 18 mm. The view distance is 90 cm.
5. E. C. Zeeman, in *Mathematics and Computer Science in Biology and Medicine* (Proceedings of a Conference held by the Medical Research Council in Association with the Health Departments, Oxford, England, July 1964), p. 277.
6. For the configural superiority effect, see, for example, N. Weisstein and C. S. Harris, *Science* **186**, 752 (1974); J. D. Schendel and P. A. Show, *Percept. Psychophys.* **19**, 383 (1976); J. L. McClelland and J. Miller, *ibid.* **26**, 221 (1979); J. Pomerantz, L. Sager, R. Stoever, *J. Exp. Psychol.: Human Percept. Perform.* **3**, 422 (1977); A. Williams and N. Weisstein, *Mem. Cognit.* **6**, 85 (1978).
7. S. E. Palmer, *Mem. Cognit.* **6**, 91 (1978).
8. The target line was about 3 minutes of visual angle wide and 53 minutes long at the viewing distance of 90 cm. The line segments consisted of the context, 6 minutes wide and 2°40 minutes long at the same viewing distance.
9. The target lies were about 3 minutes wide and 53 minutes long at the viewing distance of 90 cm. The width of the curved line of the circle was 5 minutes and its diameter 56 minutes at the same view distance.
10. S. E. Palmer, in *Representation and Organization in Perception*, J. Beck and F. Metelli, Eds. (Erlbaum, Hillsdale, N.J., in press).
11. M. Minsky and S. Papert, *Perceptrons* (MIT Press, Cambridge, Mass., 1972).
12. J. J. Gibson, *The Ecological Approach to Visual Perception* (Houghton Mifflin, Boston, 1979).
13. S. Grossberg, *Behav. Brain Sci.* **3**, 385 (1980).
14. Supported by NSF grant BNS79-24062 to J. L. McClelland and a grant from the Sloan Foundation to the Cognitive Science Program. I thank J. L. McClelland and D. A. Norman for their advice and careful reviews of several drafts. Helpful comments came from B. duBoulay, M. Hayhoe, S. Link, D. I. A. Macleod, and M. Oswald.

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Maternal Ethanol Exposure Induces Transient Impairment of Umbilical Circulation and Fetal Hypoxia in Monkeys

Abstract. *When ethanol was administered intravenously to pregnant monkeys, a transient but marked collapse of umbilical vasculature was observed uniformly within about 15 minutes. The ethanol-induced impairment of umbilical circulation produced severe hypoxia and acidosis in the fetus; recovery occurred during the succeeding hour. This striking interruption of feto-placental circulation may explain one of the mechanisms of mental retardation, a frequent manifestation in children afflicted with fetal alcohol syndrome.*

Alcohol abuse throughout the world is on the rise (*1*). Among women of reproductive age, ethanol consumption is increasingly prevalent. Epidemiological studies have shown that ethanol consumption during pregnancy causes increased perinatal mortality and morbidity (*2*). One out of 750 infants born in the United States manifests some characteristics of fetal alcohol syndrome (FAS), resulting from maternal consumption of ethanol during pregnancy (*3*). Psychomotor retardation in FAS children has been demonstrated—their average IQ was 67 with a dispersion of 50 to 83 (*4*). Specifically, FAS is composed of four major anomalies: (i) craniofacial dysmorphism, (ii) intrauterine and postnatal growth retardation, (iii) retardation of psychomotor development, and (iv) nonspecific malformations (*5, 6*).

While conducting laboratory studies (with monkeys as the test animals) on the kinetics of ethanol transfer across the placenta to the fetus, we observed that 10 to 15 minutes after ethanol was administered to the mother the vasculature of the umbilical cord collapsed. Subsequent recovery of umbilical function from this flacid state occurred during the next hour. The present study was designed to investigate the concurrent metabolic consequences to the fetus of this observed ethanol-induced transient impairment of umbilical circulation.

Rhesus (*Macaca mulatta*) and cynomolgus (*Macaca fascicularis*) monkeys at 120 to 147 days of gestation (term is 167 days) were used in all experiments. These primates had no exposure to ethanol or other exogenous agents prior to these experiments. Maternal body

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