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An advantage for concavities in shape perception by chimpanzees (*Pan troglodytes*)

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Abstract

The significance of concavity in object shape perception by chimpanzees (*Pan troglodytes*) was investigated in a matching-to-sample procedure. For the task, chimpanzees were required to choose a polygon stimulus that was identical in shape to a sample. The incorrect alternative was defined by the addition or subtraction of a concave or convex apex. Chimpanzees were more sensitive to the concave deformation than to the convex deformation. This tendency conforms to the theories of human visual perception that have treated concave features as important factors in reconstructing three-dimensional structures from two-dimensional images. Our results suggest that shape representation in chimpanzees is similar to that in humans and that chimpanzees visually process two-dimensional images in the same manner as humans.

Keywords: Chimpanzee; Concavity; Convexity; Object perception; Shape representation

1. Introduction

Among visual features, object shape has an important role in human object perception (e.g., Biederman, 1987; Biederman and Ju, 1988; Marr, 1982; Ullman, 1996). Shape is a strong determinant in isolating a visual "object" from its environmental background. It is also an important information source for reconstructing a three-dimensional, real-world object from a two-dimensional image. Studies on the characteristics of human object perception have verified the role of various shape parameters, such as contour curvature (e.g., Hoffman and Richard, 1984), symmetry (e.g., Vetter et al., 1994), and colinearity and co-curvilinearity of the contour component (e.g., Boucart et al., 1994). In this study we tested negative (concavity) and positive (convexity) curvatures of the contour line.

A negative (concave) or positive (convex) contour apex is the point at which the curvature is locally maximal as the contour bends toward or away from the interior of the shape. The processing of these apexes, especially that of concavities, plays an important role in theories of object perception (e.g., Biederman, 1987; Marr and Nishihara, 1978). The theories put forward by Biederman (1987) and Marr and Nishihara (1978) suggested that a representation of the object is constituted by separate components of the image and the relationships among them and that the points of deep concavity on the shape contour could serve as candidates for the part boundaries. In the early stages of visual processing, concavity cues may indicate the discontinuity of the object and may be used to segment a representation of the image into separate elemental units to describe a visual scene. Previous studies have shown that the rule of part boundary at the point of contour concavity is compatible with explanations of several visual phenomena, such as the reversal of figure and ground (Hoffman and Richard, 1984) and the perception of transparency (Singh and Hoffman, 1998).

Several studies have supported the importance of concavity in object perception by demonstrating an asymmetric sensitivity in the perception of concavity and convexity. Using visual search studies, Hulleman et al. (2000) reported search asymmetry in the detection of concavity and convexity: concave cusps among convex distractors were detected efficiently with a search rate of less than 10 ms/item, whereas the detection of convexity among concave distractors was inefficient. In a change detection paradigm, Barenholtz et al. (2003) also found an advantage in the detection of concave changes. Furthermore, Feldman and Singh (2005) mathematically corroborated the importance of negative curva-

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ture in shape representation, showing that regions of negative curvature carry greater information than corresponding regions of positive curvature in a closed contour.

From a comparative perspective, behavioural studies on object perception have been accumulated using avian species as subjects. Several studies have suggested that pigeons reconstruct a three-dimensional representation from a two-dimensional stimulus presentation (Cook and Katz, 1999) by means of "recognition by components" (Kirkpatrick-Steger et al., 1998). However, inabilities of object perception in pigeons compared to humans are also designated (Jitsumori and Makino, 2004). For example, Spetch et al. (2001) directly compared performances of pigeons and humans and showed that, unlike humans, pigeons did not produce a viewpoint-invariant representation.

Although many neurophysiological studies have investigated the neural correlation to object perception in nonhuman primates (e.g., Pasupathy and Connor, 2002; Tanaka, 1996), few behavioural studies have directly addressed the perceptual representation of objects in nonhuman primates, compared to the intensive investigations on human perception. Almost nothing is known about the role of concavity and convexity in the visual perception of nonhuman animals. To further understand shape perception and object representation in nonhuman primates, this work reports on the results of experiments with chimpanzees, which are the closest evolutionary relative to humans (Fujiyama et al., 2002; Stone et al., 2002).

Some studies have compared the shape perception of chimpanzees with that of humans. Matsuzawa (1990) trained a chimpanzee to discriminate the 26 letters of the alphabet in an identical matching-to-sample task and found that the perceived similarity of the shape of letters, estimated from the confusion errors, had much in common with results from humans obtained through similarity judgements. Tomonaga and Matsuzawa (1992) also used a matching-to-sample procedure to assess the perceived similarity of the shapes of geometric figures by chimpanzees. From nonmetric multidimensional scaling and hierarchical cluster analysis of the response time data, they found that chimpanzees perceived complex figures in a manner similar to humans, thus suggesting the perceptual dominance of outer-contour elements.

These studies imply a commonality in shape perception between chimpanzees and humans, but the importance to chimpanzees of individual features in shape representations, including concavity and convexity, is still unclear. Our aim was to test the sensitivity of chimpanzees to changes in the concavity or convexity of two-dimensional shape stimuli, in order to advance the understanding of shape representation in nonhuman primates, as well as the continuity and evolution of human object perception.

2. Materials and methods

To test the shape perception of concavity and convexity, we adopted a two-alternative matching-to-sample procedure, using two-dimensional polygons (after Barenholtz et al., 2003) on a monitor as stimuli. The chimpanzees were required to distinguish the shape of polygons from a distractor stimulus, the shape of which was deformed by adding or subtracting a concave or convex apex.

2.1. Subjects

Five chimpanzees participated in the experiments: Ai (28 years old, female), Ayumu (5 years old, male), Chloe (24 years old, female), Cleo (5 years old, female), and Pendesa (28 years old, female). The subjects were experienced in performing various perceptual-cognitive tasks, such as matching-to-sample (Matsuno et al., 2004) and visual-search tasks (e.g., Tomonaga, 2001), and were accustomed to the experimental settings used in this study.

The subjects lived with 10 other chimpanzees in an environmentally enriched outdoor compound and attached indoor residences (Matsuzawa, 2006; Ochiai and Matsuzawa, 1997). They were not deprived of food at any time during the study. The care and use of the chimpanzees adhered to guidelines of The Guide for the Care and Use of Laboratory Primates (2002) of the Primate Research Institute, Kyoto University.

2.2. Apparatus

The chimpanzees were tested in an experimental booth (~1.8 m × 1.8 m × 2.0 m) with acrylic panel walls on all four sides. The stimuli were generated on a Pentium-based computer and displayed on 21 and 22 in CRT monitors (Totoku CV-213PJ for Ayumu and Cleo and Mitsubishi TSD-221S for the other three) equipped with capacitive and surface acoustic wave touch screens. This monitor system was used to present the stimuli and was also the input device for subject responses via touch locations. The resolution of the monitors was 1024 × 768 pixels with an 8-bit color mode. The refresh rate was 75 Hz, and the display was synchronized with the vertical retrace of the monitor. The subjects observed the monitors at a viewing distance of approximately 45 cm without head restraints. The viewing distance was roughly restricted by an acrylic panel, which was attached between the monitor and subjects with an aperture for touch responses. The stimulus luminance was measured using a colorimeter (Topcon, BM-7). A universal feeder (Biomedica, BUF-310) delivered small pieces of a food reward (apples or raisins) into a food tray below the monitor. The laboratory was dimly illuminated to prevent reflections on the computer screen.

2.3. Stimuli

The stimuli were computer-generated grey-filled polygons (approximately 25 cd/m^2) against a black background (Fig. 1). Each stimulus was approximately 3.2–6.4° of the visual angle in height and width. A stimulus set consisted of three polygons: one was a "base" stimulus, and the other two were deformations of the base stimulus. The base stimulus was generated by choosing 8 or 10 apexes at random locations around an arbitrarily determined centre point, using the following constraints. Each central angle of two adjacent apexes was greater than 18.0° for eight-apex polygons and 22.5° for 10-apex polygons, and zero, two, or four apexes were concave, while the others were con-