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CATS SEE SUBJECTIVE CONTOURS

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Abstract—Behavioural techniques were used to determine whether cats are able to see subjective contours. Through several stages of testing with increasingly complex displays, cats continued to respond to a figure defined by subjective contours. This result provides the first direct evidence that a nonhuman perceives subjective contours.

Subjective contour   Cat vision   Visual illusion

INTRODUCTION

Figure 1 conveys the strong impression of a black square resting on top of four white circles, while in fact the picture consists of nothing more than four sectored disks. Studed in detail by Kaniza (1954), this compelling figure/ground illusion demonstrates that the human visual system can construct subjective contours across regions that contain no discontinuities in the image. This constructive process of boundary interpolation may be a necessary early step in the segregation of objects whose real boundaries are partially obscured. According to this line of reasoning, then, humans should not be the only species that perceive figures defined by subjective contours—other animals that must segregate objects within a crowded visual environment may also rely on boundary interpolation to separate figure from ground.

Some indirect evidence that nonhuman species see subjective contours comes from the physiological discovery of cortical cells that respond to illusory contours. These cells are found in area 18 of the monkey (von der Heydt *et al.*, 1984) and in area 17 of the cat (Redies *et al.*, 1986). In this paper, we report the first direct evidence that a nonhuman species, the cat, can actually see subjective contours.

RATIONALE

How can we demonstrate that cats see a subjective square when viewing a display like the one shown in Fig. 1? To generate conclusive evidence requires demonstrating that cats recognize the global figure defined by the subjective contours, not merely the particular configuration of sectored disks that creates that shape. Toward this end, we devised a movie display that makes recognition of the sectored disk pattern impossible while leaving the subjective square clearly visible. Three frames from our display are shown in Fig. 2a. When these frames are shown in succession, a subjective square appears to move down the screen and the sectored disks not "covered" by the square appear to spin about their centers. The subjective square is readily seen over a range of frame durations. When the four sectored disks forming the subjective square are replaced by some other disk configuration, such as the one shown in Fig. 2b, global downward motion disappears and only local spinning motion is seen. Not only is the correspondence between the identical disk patterns not detected, the pattern itself is not seen and the display is indistinguishable from one in which all of the disks spin in a random fashion. We have confirmed these observations on human observers using forced choice testing (see Fig. 3). Hence, if cats can discriminate between the subjective square movie shown in Fig. 2a and a movie in which the disks spin randomly, we would assert that the cats must be seeing the subjective square.

METHOD

We tested two young, female cats using a two-choice discrimination procedure (Blake and

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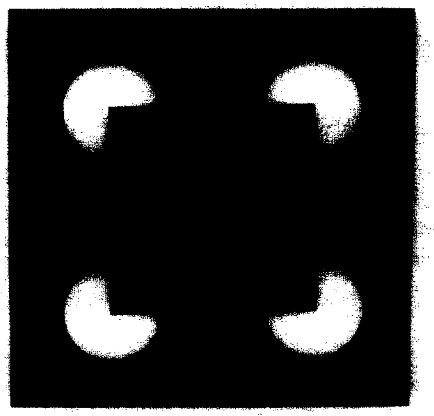

Fig. 1. Sectored disks which can generate illusory figures, in this case an illusory square.

Holopigian, 1985). While housed in a comfortable restraining box, the cat extended its head through a hole located at one end of the box to gain access to a pair of response keys and a food delivery port. Located 50 cm directly in front of the cat was a monochrome television monitor (Conrac model 2600, 752 × 480 pixels) upon which two computer-generated movie sequences could be simultaneously displayed, one on each side of the monitor. On each trial, the movie on one side of the screen contained an array of sectored disks that created the impression of a subjective square moving up and down in apparent motion; the other side displayed a foil composed of an array of sectored disks that did not define a subjective square. Each disk was 2.5 deg in dia., and the center-to-center distance beween disks was 5 deg. The luminance of each white disk was 8 ft L, and the background was 0.04 ft L.

Using standard operant conditioning procedures, each cat was trained to touch one of two response keys to indicate on which side of the display—left vs right—the subjective square

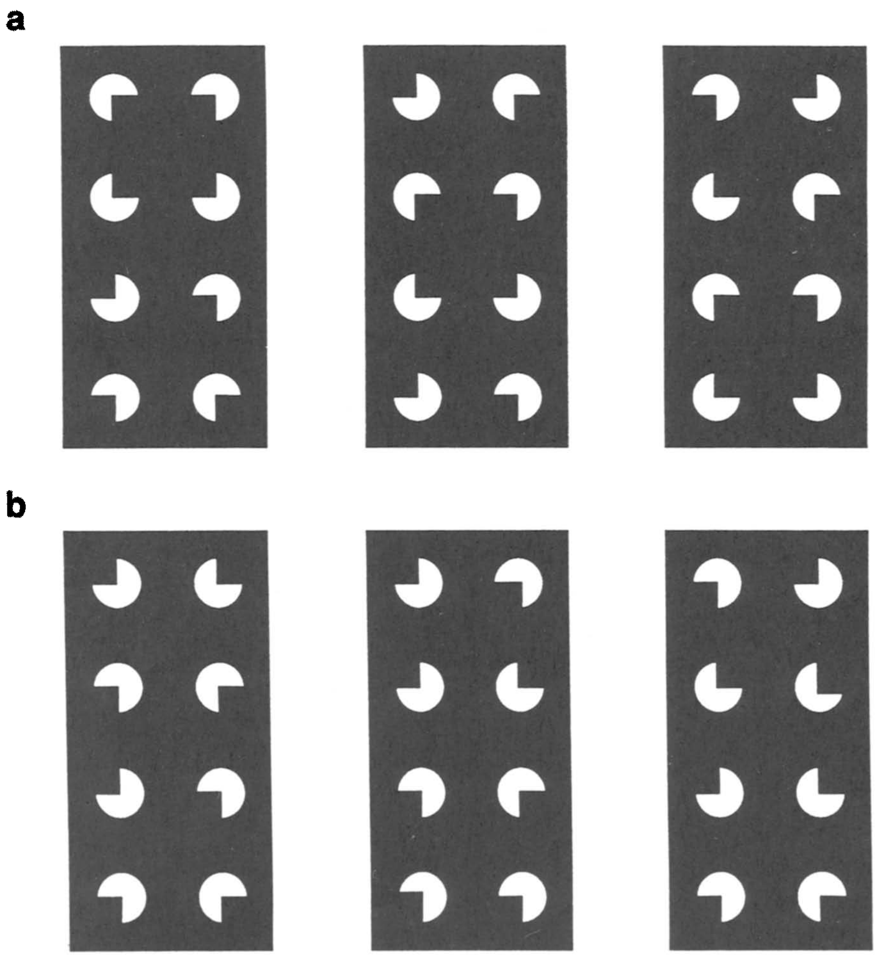

Fig. 2. (a) Three frames from a movie of a subjective square undergoing apparent motion. The perception of the square is vivid over a range of frame durations. (b) Three frames from the control movie in which a given configuration of sectored disks is displaced over frames. This configuration occupies the same position as that occupied by the subjective square in **a**. With the configuration illustrated in **b**, neither apparent motion, a subjective figure nor the configuration itself is seen at any movie speed.

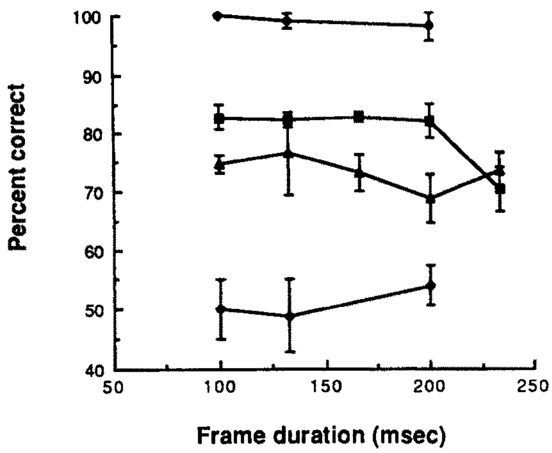

Fig. 3. Individual results for two cats (▲, ■) and average results for five humans (◆) tested on a two alternative forced choice task. Filled symbols give the results for a display like that shown in Fig. 2a, in which a subjective square undergoes apparent motion. Open symbols give the results for a display like that shown in Fig. 2b, in which a given configuration of sectored risks is displaced from frame to frame without generating an illusory shape of apparent motion. The chance performance of human observers on this latter condition indicates that they were unable to discriminate the control movie from one in which sectored disks rotated randomly from frame to frame. The total movie duration was constant of all movie speeds. Human observers were tested on 50 trials for each condition; cats were tested on 400 trials for each condition.

appeared, with the correct side varying randomly from trial to trial. Correct responses were immediately rewarded by delivery of a small amount of food followed in 3 sec by the next trial; incorrect responses led to a 5 sec time-out period before the next trial, with no food delivery. The animal was allowed up to 4 sec to view the display before responding. Both cats received their daily ration of food in this testing situation, with each session typically consisting of 200 trials. All aspects of the daily testing schedule were controlled by computer. The experiment involved four stages, and each cat was graduated to the next more difficult stage following 3 days in a row on which performance was 80% correct or better.

RESULTS

Stage 1

For initial training, the correct side depicted a black subjective square that appeared to move up and down over a background of eight stationary white disks. In each successive frame of the movie, the four sectored disks defining the subjective square shifted up or down by one row, creating the conditions for apparent motion. All eight disks on the incorrect side were whole, with no missing sectors. Both cats learned this discrimination rapidly.

Although this stage 1 display generated the compelling illusion of a square moving continuously up and down, we of course could not be certain that the cat based its discrimination on the subjective square; several other potential cues (luminance, temporal changes, presence of local pattern elements) distinguish the correct side from the incorrect side. In the next stages of the experiment, these extraneous cues were systematically eliminated.

Stage 2

In stage 2 the correct side again depicted the subjective square moving up and down on top of a set of white disks, but the incorrect side now included four stationary sectored disks that did not form subjective contours. With this stage 2 display, the cat could no longer base its decision simply on the presence of sectored disks or on overall differences in luminance. Other cues (e.g. temporal changes), however, remained available. Both cats reached the criterion level of performance within 8 days and were graduated to the third stage.

Stage 3

In stage 3, the cats were confronted with displays in which all disks on both sides of the display were sectored, with only those on the correct side forming the stimulus conditions sufficient for generating the moving subjective square. Over several days we increased the number of sectored disks undergoing rotation on both sides of the display, so that by the end of stage 3 every sectored disk rotated from frame to frame. As the display was made more complicated during stage 3, performance of both cats remained consistently above chance and typically above 70%.

To summarize, at the conclusion of stage 3 both sides of the display contained sectored disks that rotated from frame to frame. On the correct side, four of the disks had sectors that formed the subjective square and the positions of these four disks shifted systematically within the array. On the incorrect side, no pattern of four sectored disks was ever consistently present over successive frames, though individual sectored disks appeared to rotate just like those on the correct side. It is noteworthy that we generated multiple versions of this stage 3 display and used different versions from day to day, to insure that cats could not perform successfully by learning some arbitrary pattern of sectored disks in a single display. The cats consistently performed above chance on all versions of the stage 3 display.

Stage 4

To assure ourselves further that the cats were seeing the subjective square and not simply recognizing the four-disk configuration producing the square, we tested the cats at a number of movie speeds. If the cats were relying on recognition of the sectored disk configuration, we expected their performance to deteriorate as frame duration decreased, since shorter frame durations would give the cat less time to inspect individual frames for a particular sectored disk configuration. (The reader may have noticed that it takes longer to detect the configuration in Fig. 2b than it does to detect the one in Fig. 2a). If, however, the cats were seeing the subjective square, changes in frame duration would merely alter the apparent velocity of movement of the square. The results (Fig. 3) show no effect of frame duration on performance and, hence, further support the conclusion that cats can see subjective contours.

After completing these four stages of the experiment we felt confident that the cats could not be basing their performance on the recognition of a particular disk configuration. Still, it could be argued that the cat accurately distinguished the correct from the incorret side by detecting apparent movement of one of the corners of the illusory square, without actually seeing the square formed by the illusory contours. This possibility seems remote for two reasons. First, if the cat were not seeing the subjective square, it should have seen stationary disks that appeared to spin. This conclusion is drawn from the constraint of spatial proximity (Ullman, 1979), a constraint that arises from the properties of objects in the physical world. Spatial proximity dictates the establishment of correspondence between missing sectors of the same disk rather than between disks with the same missing sector. Because both target and foil displays contain equal numbers of these "spinning" disks, discrimination based on this cue should be impossible. For human observers, the task is indeed impossible. Second, even if the cat did see apparent motion between disks with the same missing sector, the multiple possibilities for a match would generate motion in several directions on both sides of the display. This would also result in a failure to discriminate between the target and the foil.

Nontheless, because of the remote possibility that the cats were using an apparent motion cue produced by the consistent movement of a disk configuration, we tested the cats on a display containing a subset of sectored disks that did not generate subjective contours but did move consistently from frame to frame. We reasoned that if the cat were basing its performance on the detection of apparent motion of one of the corners of the illusory shape, and not the global square itself, the cat's performance should be unaffected since that local motion cue is contained in the revised display. The cats were tested on 150 trials of both the final stage 4 display and of the revised "local cue" display. Both cats performed at chance levels on the display that did not contain subjective contours while performance remained above chance on the display that did contain subjective contours. The difference in performance between these two conditions was statistically significant ($P < 0.01$), confirming that cats, like humans, can discriminate between the target and foil displays only if the target contains stimulus conditions that produce subjective contours.

CONCLUSION

Strictly speaking, it is impossible to be certain that a cat actually *sees* a square defined by subjective contours when looking at a display like that illustrated in Fig. 1. For that matter, the same logical impossibility applies to any species, humans included. Still, we have shown that cats are able to perform accurately on a task that humans find possible based on the perception of a subjective square. Moreover, we have found that cats fail on that task under stimulus conditions where humans fail to perceive a subjective square and, hence, perform at the level of chance. This comparability of performance leads us to conclude that cats and humans both perceive shapes defined by illusory contours.

The origin of subjective contours is a question of considerable theoretical controversy (see review by Halpern, 1981). We believe the present results have some bearing on this controversy. Some theorists (Gregory, 1973; Rock, 1985) argue that subjective contours arise from a conceptually based, cognitive process. For instance, it has been asserted that the global form defined by subjective contours represents an "inference" that is unrelatable in any direct sense to activity within primary visual areas in the brain (Gregory, 1983). In view of the present results, these cognitive theorists are now forced to conclude that cats, not just humans, employ reasoning-like processes to interpret subjective contour displays. Advocates of cognitive theories of subjective contours will need to specify the nature of the putative knowledge-driven processes in terms plausibly applicable to non-human mammals.

Other theorists (Marr, 1984) attribute these kinds of figure/ground illusions to low-level neural machinery that segments the retinal image into biologically relevant features. This latter class of explanations, in other words, focuses on automatic, data-driven processes that do not involve inferences, hypotheses or other cognitive-like operations. The discovery that cats see subjective contours poses no difficulties for this class of theories. Indeed, this discovery reinforces the conjecture that boundary interpolation is a necessary early step in the segregation of objects whose real boundaries are partially obscured.

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