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Changes in area affect figure–ground assignment in pigeons

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ABSTRACT

A critical cue for figure–ground assignment in humans is area: smaller regions are more likely to be perceived as figures than are larger regions. To see if pigeons are similarly sensitive to this cue, we trained birds to report whether a target appeared on a colored figure or on a differently colored background. The initial training figure was either smaller than (Experiments 1 and 2) or the same area as (Experiment 2) the background. After training, we increased or decreased the size of the figure. When the original training shape was smaller than the background, pigeons' performance improved with smaller figures (and worsened with larger figures); when the original training shape was the same area as the background, pigeons' performance worsened when they were tested with smaller figures. A smaller figural region appeared to improve the figure–ground discrimination only when size was a relevant cue in the initial discrimination.

1. Introduction

"If one tried to bring some order into [our surrounding] medley, one would probably begin by distinguishing things and not-things (p. 70)." As Koffka (1935) pointed out more than seven decades ago, it would be impossible to make sense out of our visual environment if we were unable to organize the different visual elements in terms of figures (objects) and background (the space between objects). Figures are shaped elements that: (a) summon our attention, (b) arouse our interest, (c) target our actions, and (d) must be recognized and remembered. In contrast, the background has no shape or boundaries; it is simply the space between and around objects.

Figure–ground assignment is a fundamental visual process which was first described in the pioneering work of Rubin (1915/1958). Rubin detailed many of the phenomenological disparities between regions that are perceived as figures (possessing shape, appearing in front of the background, being more intense and vibrant in color, imposing and commanding one's attention) and regions that are perceived as ground (lacking shape, extending behind the figures, being less intense in color and salience). Rubin also identified some of the factors that determine which regions of the visual field will become figures and which will become ground. All else being equal: (a) small regions are more likely to be identified as figures, (b) surrounded regions are normally perceived as figures, and (c) vertically or horizontally oriented areas, rather than diagonally oriented areas, are more frequently deemed to be figures than ground.

Later research has revealed additional stimulus factors which govern the assignment of figure and ground. Some of these factors are: (d) symmetrical regions are more likely to be identified as figures than ground (Bahnsen, 1928), (e) convex regions tend to be perceived more often as figures and concave regions as ground (Kanizsa & Gerbino, 1976, Metzger, 1935), (f) regions that contrast most with the general illumination are considered figural (Koffka, 1935), (g) regions depicting familiar and meaningful objects are taken as figures rather than ground (Peterson, 1994), and (h) regions located in the lower part of a display are more frequently perceived as figures than when the same regions appear in other locations (Vecera, Vogel, & Woodman, 2002).

In the present study, we explored the role of differently sized areas on the discrimination of figures and backgrounds. Although smaller regions are more likely to be perceived as figures, it is not yet clear why this is the case. One hypothesis, based on functional considerations, suggests that cues for figure–ground discrimination reflect regularities in the environment which help the viewer to identify the most likely objects in a complex visual scene. Smaller regions may thus be perceived as figures because the most probable interpretation of the scene is that there is a smaller object in front of a larger object rather than that there is a hole in the larger object (Palmer, 1999).

Another account derives from the neural network model offered by Vecera and O'Reilly (1998, 2000). These authors proposed that figure–ground assignment results from competition among many interconnected units arranged in two layers: the first layer responds to edges, whereas the second layer represents figural

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regions. Vecera and O'Reilly's model is more likely to assign figural status to a smaller region because many units which are activated by that region share excitatory connections and, consequently, activate each other, thereby increasing the overall activation of that region. As a region becomes larger, more units which are activated by that region do not share connections and, thus, cannot directly support one another. Although this explanation awaits neurobiological support, other aspects of the model have been verified by neurophysiological studies (see, for example, Zhou, Friedman, & Von Der Heydt, 2000).

Figure–ground assignment has been extensively explored in humans, but very little research has been conducted on how animals segregate figure from background. Still, there is some evidence from neurobiological research suggesting that neurons in the primate visual cortex may be sensitive to figure–ground status. In several studies, Lamme and colleagues (Lamme, 1995; Supèr, Spekreijse, & Lamme, 2001) trained rhesus monkeys to identify a figural region (defined by common orientation of line segments or by common motion) by making a saccadic eye movement toward its position. Neurons in primary visual cortex, area V1, were found to fire more rapidly when the element activating their receptive fields was located within a figural region than when it was located within a background region (but see Rossi, Desimone, & Ungerleider, 2001). Other evidence indicates that the responses of edge-sensitive neurons in areas V1 and V2 are determined by the side of the figural region to which this edge belongs, suggesting that figure–ground assignment occurs relatively early in the course of visual processing (Lamme, 1995; Supèr, Spekreijse, & Lamme, 2003; Zipser, Lamme, & Schiller, 1996; Zhou et al., 2000).

As we noted earlier, it seems clear that area is one of the fundamental cues that affect figure–ground assignment in humans, irrespective of the different explanations for this "smaller area" effect. Does area similarly affect figure–ground assignment in animals?

One particular behavioral study by Herrnstein, Vaughan, Mumford, and Kosslyn (1989) can be considered to be closely related to the distinction between figures and backgrounds in pigeons. Herrnstein et al. presented pigeons with a closed white outline along with a white dot which could either be placed inside or outside the white outline. Birds were trained to peck a response key when the dot fell inside the white outline and to withhold pecking when the dot fell outside the white outline (or vice versa for different birds). When the outline's interior and exterior were both black, pigeons did not learn the discrimination; they did so only when the outline's interior was red and its exterior was black.

It might be that the disparity in color between the regions helped the pigeons to perform the task in terms of figure and background; if the identical color were both inside and outside the outline, then the inside region might simply be seen to be a continuation of the same colored outside region, transforming the display into a large background and rendering the discrimination impossible. So, it seems that local color disparities may have supported the pigeons' discrimination learning in Herrnstein et al.'s experiments.

Additionally, Herrnstein et al.'s go/no go procedure did not permit direct comparison of figure and ground responses, either in terms of accuracy or reaction time. Thus, this go/no go method cannot fully reveal the behavioral consequences of figure–ground assignment that human observers exhibit, such as an advantage for detecting targets on figures over those on grounds (Nelson & Palmer, 2007).

In an attempt to directly study pigeons' figure–ground segregation, Lazareva, Castro, Vecera, and Wasserman (2006) trained birds to discriminate whether a target appeared on a colored figural shape or on a differently colored background (the same colors were randomly used as figure and background, so that color alone could not be used as a cue to solve the visual discrimination). When the display appeared on the screen, pigeons had to peck the target a certain number of times. After completing this observing response requirement, two choice keys appeared to the left and right of the display—one key representing the "figure" response and the other key representing the "background" response—and the pigeons had to select the appropriate key to receive food reinforcement. Not only did the birds master this discrimination to high levels of accuracy, but they also showed a strong figural advantage in terms of higher accuracy for *figure* trials than for *background* trials. The figural benefit was seen in reaction times as well. Pigeons pecked the target faster when it appeared on the figure than when it appeared on the background and they were faster to report the correct choice on *figure* trials than on *background* trials. Note that nothing in this experimental procedure encouraged the pigeons to attend preferentially to the figural region because the target appeared equally often on the figure and on the background.

As Fig. 1A illustrates, the visual displays involved in the pigeons' discrimination (Original Training Displays, middle row) contained a smaller and surrounded region (the figure) and a larger surrounding region (the background). Therefore, figure and background were defined by two of the strongest cues that determine figure–background organization: size and surroundedness. As noted earlier, humans normally perceive a small surrounded region to be a figure.

In the present study, we evaluated the effect of different figure sizes on pigeons' figure–ground discrimination. Because smaller regions should be more likely to be perceived as figures and larger regions should be more likely to be perceived as background, if we were to decrease the proportionate area occupied by the figure, then the figure–ground discrimination should become easier. The opposite relationship should also hold: if we were to increase the proportionate area occupied by the figure, then the figure–ground discrimination should become more difficult.

Relative size might also affect reaction times. It could be the case that, when the size of the figure is small, detecting the target is even faster on *figure* trials and longer on *background* trials. Therefore, the disparity in target detection time between *figure* and *background* trials might be even greater when the figure is small. Time to report the location of the target (whether it is on the figure or on the background) might be similarly influenced by different sizes of the figure.

Here, we report the results of two experiments on figure–background discrimination in pigeons. In Experiment 1, the initial training figure was smaller than the background; in Experiment 2, the initial training figure was either smaller than the background or the same area as the background. We initially evaluated the effect of changes in figural area on discrimination accuracy by presenting different figure sizes as nondifferentially reinforced probe trials. We subsequently presented different figure sizes as differentially reinforced trials to evaluate the effect of changes in figural area on target detection time and choice response time. Very different patterns of discrimination accuracy and reaction time were supported in these two experiments, with important implications for the processes of figure–ground segregation.

2. Experiment 1

2.1. Method

2.1.1. Subjects

The subjects were four feral pigeons (*Columba livia*) maintained at 85% of their free-feeding weights by controlled access to food. Grit and water were available ad libitum in their home cages. The pigeons had earlier been trained to perform the figure–ground discrimination using original training displays (displayed in the