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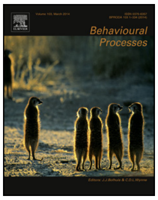

No evidence for feature binding by pigeons in a change detection task

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ABSTRACT

We trained pigeons to respond to one key when two consecutive displays were the same as one another (no-change trial) and to respond to another key when the two displays were different from one another (change trial; change detection task). Change-trial displays were distinguished by a change in all three features (color, orientation, and location) of all four items presented in the display. Pigeons learned this change-no change discrimination to high levels of accuracy. In Experiments 1 and 2, we compared replace trials in which one or two features were replaced by novel features to switch trials in which the features were exchanged among the objects. Pigeons reported both replace and switch trials as "no-change" trials. In contrast, adult humans in Experiment 3 reported both types of trials as "change" trials and showed robust evidence for feature binding. In Experiment 4, we manipulated the total number of objects in the display and the number of objects that underwent change. Unlike people, pigeons showed strong control by the number of feature changes in the second display; pigeons' failure to exhibit feature binding may therefore be attributed to their failure to attend to items in the displays as integral objects.

1. Introduction

Recent research suggests that human visual short-term memory (VSTM) often stores bound representations of objects instead of individual object features. In one representative experiment, human participants were shown two consecutive displays containing from one to four colored bars and asked to report whether the two displays were the same or different (Vogel et al., 2001). On some trials, the participants were asked to remember only the color (or the orientation) of the bars, whereas on other trials they were asked to retain both color and orientation information. If color and orientation were stored independently, then due to the limited capacity of VSTM, participants should have shown a diminished ability to correctly report whether the two displays were the same or different when both features had to be remembered and reported. Yet, their performance was equivalently accurate in both conditions suggesting that VSTM stores integrated, bound representations of objects instead of independent lists of object features.

Similar to the primate visual system, the avian visual system processes visual information along at least two separate dimensions (shape and motion) localized in different brain areas (Laverghetta and Shimizu, 1999; Shimizu et al., 2010). Thus, it seems logical to assume that, just like the primate brain, the avian brain should be able to switch from coding individual features to representing unitary, bound objects. Although binding in avian low-level vision is relatively well-established (Cook, 1992; Cook et al., 1997, 1996), its participation in VSTM is less clear.

The problem of binding originally arose in the context of low-level perception: Once the visual system encodes elemental features, it must at some level establish which features belong to which object. Feature integration theory posits that elemental features of the object are detected early and in parallel, whereas binding of these features to construct *object files* requires attention, occurs later, and proceeds serially (Treisman, 1998, 2006). Consequently, visual search for an object that can be detected by an elemental feature (e.g., a red target among green distractors) is predicted to be faster and more accurate than search for an object defined by a conjunction of features (e.g., a red square target among green squares and red circles). Just like humans, pigeons were reported to be more accurate and faster in detecting targets in elemental displays than in conjunctive displays, demonstrating that the avian visual system detects and encodes elemental features early and, possibly, preattentively (Cook et al., 1997, 1996; Cook, 1992). But, does it combine these elemental features into an object file? And, if it does, then are these object files similar to those found in humans?

According to feature detection theory, the process of creating object files can sometimes lead to illusory conjunctions. For

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example, the brief presentation of a display containing a red X, a blue X, and a green T occasionally produces a report of a blue X or a red T; in other words, when people are prevented from focusing attention on individual objects, they sometimes join object features incorrectly (Treisman and Schmidt, 1982). Similarly, Katz et al. (2010) found that pigeons occasionally committed binding errors indicative of illusory conjunctions. For example, having been trained to select the left hopper when a red U and a green T are presented, a bird might incorrectly select the left hopper when a green U and a red T are presented due to erroneous conjunctions between color and shape.

What about binding in avian VSTM? Recent research suggests that human visual working memory stores two to four object files containing bound features such as color, location, or shape (Treisman, 2006; Vogel et al., 2001; Luck and Vogel, 1997). Storing object files instead of individual object features seems intuitively plausible due to the limits of a small VSTM capacity (Cowan, 2000; Miller, 1956). Object files can be thought of as a form of chunking, a well-known basic principle of human memory that allows us to increase the number of correctly encoded and recalled items. Pigeons also have a comparably small VSTM capacity (Gibson et al., 2011; Wright, this issue) and use chunking in serial learning tasks (Terrace, 1987). We do not yet know; however, whether pigeons also store bound representations of objects in their short-term memory.

Some indirect evidence suggests that pigeons can learn a task that is impossible to solve without correctly binding the features belonging to the same stimulus. George and Pearce (2003) trained pigeons to respond to a compound target stimulus (e.g., horizontal red lines on the left and vertical green lines on the right) and to refrain from responding to a distractor (e.g., vertical red lines on the left and horizontal green lines on the right); in other words, the pigeons had to simultaneously attend to both color and orientation dimensions in order to solve these discriminations. Subsequent tests demonstrated that pigeons learned this task by using feature-bound stimulus representations rather than by using a form of a template matching. However, being able to learn the task that requires binding does not necessarily imply that pigeons use bound representations of objects in their VSTM in other discrimination tasks, as people do.

In our study, we chose a change detection task as a means of studying feature binding in pigeons. Previous research has shown that pigeons can learn a traditional change detection task (Wright and Elmore, 2010). Moreover, just as in humans, pigeons' ability to detect changes improves when more items in the display change, indicating an ability to maintain multiple items in VSTM (Gibson et al., 2011; Wright, this issue). Because the change detection task has been successfully used to study feature binding in humans (Vogel et al., 2001), we anticipated that it would also be effective for studying feature binding in pigeons.

2. Experiment 1

In our first experiment, we trained pigeons to respond to one key when two consecutive displays remained unchanged and to respond to another key when the second display differed from the first, a classic change-detection task. Once the pigeons had acquired the discrimination, we conducted several tests designed to explore whether pigeons performed this task by storing independent lists of features or integrated, bound object representations.

2.1. Method

2.1.1. Subjects

The subjects were 4 feral pigeons (*Columba livia*) housed in individual cages in the Psychology vivarium at The University of Iowa. The birds were maintained at 85% of their free-feeding weights by the delivery of food pellets during experimental sessions and by mixed grain after experimental sessions. Grit and water were freely available in the home cages. The pigeons had served in unrelated studies prior to this experiment. One bird did not learn the task even after extensive training; therefore, the final sample comprised 3 birds.

2.1.2. Apparatus

The experiment used 36 × 36 × 41 cm operant conditioning chambers detailed by Gibson et al. (2004). The boxes were located in a dark room with continuous white noise. The stimuli were presented on a 15-inch LCD monitor (NEC MultiSync LCD1550 V, Melville, NY) located behind an AccuTouch resistive touch screen (Elo TouchSystems, Fremont, CA). A food cup was centered on the rear wall level with the floor. A food dispenser delivered 45-mg food pellets through a vinyl tube into the cup. A houselight (an incandescent 28 V–0.1 Amp lamp, Eiko, model 1820, Taiwan, with filament type C-2F) on the rear wall provided illumination during the session. Each chamber was controlled by an Apple® eMac® computer.

A single central 9 × 9 cm area in the center of the computer monitor was used to present the stimulus display; the rest of the central area was black. The response buttons were shown on the left and the right sides of the stimulus display. Responses that occurred beyond these areas were not recorded and could not advance the trial. The experimental procedure was programmed in HyperCard, Version 2.4 (Apple Computer, Inc., Cupertino, CA).

2.1.3. Construction of training stimulus displays

Fig. 1 illustrates the construction of a stimulus display. Each stimulus display included four bars that could vary in color, orientation, and spatial location placed on a light grey background. At

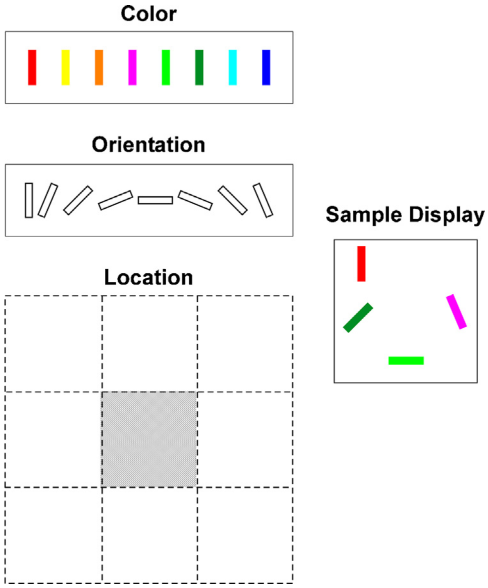

Fig. 1. Construction of stimulus displays. Each display used four out of eight possible features from three dimensions (color, orientation, and location) on a light grey background (removed for illustrative purposes). A 3 × 3 matrix was used to create eight possible locations (the center location was never employed). The features were selected and combined randomly on each trial.