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Selective attention and pigeons' multiple necessary cues discrimination learning☆

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ABSTRACT

We deployed the Multiple Necessary Cues (MNC) discrimination task to see if pigeons can simultaneously attend to four different dimensions of complex visual stimuli. Specifically, we trained eight pigeons on a simultaneous discrimination to peck only 1 of 16 compound stimuli created from all possible combinations of two stimulus values from four separable visual dimensions: shape (circle/square), size (large/small), line orientation (horizontal/vertical), and brightness (dark/light). Some pigeons had CLHD (circle, large, horizontal, dark) as the positive stimulus (S+), whereas others had SSVL (square, small, vertical, light) as the S+. All eight pigeons acquired the MNC discrimination, suggesting that they had attended to all four dimensions. Learning rate was similar to all four dimensions, with learning along the orientation dimension being a bit faster than along the other three dimensions. The more dimensions along which the S−s differed from the S+, the faster was learning, suggesting an added benefit from increasing perceptual disparities between the S−s and the S+. Of particular note, evidence of attentional tradeoffs among the four dimensions was much weaker with the simultaneous task than with the successive task. We consider several reasons for this empirical disparity.

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others.

These famous lines of William James (1890/1950, pp. 403–404) emphasize the phenomenology of selectively attending to some stimuli and ignoring others. However obvious James's mentalistic proposal may seem to us, it is utterly useless to researchers who are interested in the developmental and comparative psychology of selective attention—babies and baboons do not spontaneously relate their states of mind to us. Any hope of gaining objective insight into the nature of selective attention requires behavioral study—even in the case of verbal adults.

In this connection, Herbert Spencer Jennings later pioneered a behavioral approach to the study of psychological phenomena, like attention. For Jennings, attention is not a conscious mental state; rather, "at the basis of *attention* lies objectively the phenomenon that the organism may react to only one stimulus even though other stimuli are present which would, if acting alone, likewise produce a response (1906/1976, p. 330)." The organism can then be said to attend to the particular stimulus to which it responds.

This equating of attention with the stimulus control of overt behavior was most carefully and explicitly stated by George Reynolds (1961) in regard to his well-known study of pigeons' visual discrimination learning, in which redundant relevant cues (color and shape) were associated with reinforced or nonreinforced key pecking. Reynolds proposed that, "an organism attends to an aspect of the environment if independent variation or independent elimination of that aspect brings about variation in the organism's behavior (p. 203)."

Reynolds' pioneering experiments showed "that a pigeon may attend to only one of several aspects of a discriminative stimulus. Every part of the environment that is present when a reinforced response occurs may not subsequently be an occasion for the emission of that response (p. 208)." Therefore, according to Reynolds, "attention refers to the controlling relation between a stimulus and

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responding. An organism attends to a stimulus when its responding is under the control of that stimulus (p. 208).”

Many different experimental methods have been deployed to study selective attention in animals (Riley and Leith, 1976; Sutherland and Mackintosh, 1971; Thomas, 1970; Zentall, 2012). However, none of these methods affords researchers the opportunity to study the *dynamics* of selective attention while discrimination learning is actually unfolding. We therefore developed the Multiple Necessary Cue (MNC) task, which allows the concurrent monitoring of stimulus control by several different physical dimensions as learning progresses. Since 1993, we have deployed the MNC task to study a variety of issues in discrimination learning, with selective attention emerging as one of our prime concerns (Chatlosh and Wasserman, 1993; Gottselig et al., 2001; Kirkpatrick-Steger and Wasserman, 1996; Kirkpatrick-Steger et al., 2000; Soto and Wasserman, 2010, 2011; Vyazovska et al., 2014; Wasserman et al., 2002).

For instance, in the course of our studies of stimulus control by geons and their spatial relations in object discrimination (reviewed by Wasserman and Biederman, 2012), we discovered that the MNC task could yield very useful information. In one project, Kirkpatrick-Steger and Wasserman (1996) arranged a successive go/no go version of the MNC discrimination procedure to teach eight pigeons to peck just 1 of 16 pictorial stimuli, each of which displayed two abutting shapes. As one example of a positive stimulus (S+), a wedge would be located to the right of a cube. The remaining three locations of the wedge relative to the cube (left of, above, below) were negative stimuli (S−s); so too were all four locations (right, left, above, below) of three different shapes (cylinder, cone, handle).

The birds rapidly learned this go/no go discrimination task—pecking the 1 S+ at a much higher rate than any of the 15 S−s—thereby documenting stimulus control by both geon identity and spatial relation. Most interestingly, across all of the pigeons, there was an *inverse* relation between stimulus control by component shape and component location: that correlation was large and statistically significant, −.84. This strong negative correlation suggests that the more stimulus control was acquired by one aspect of the line drawings, the less control was acquired by the other—a classic *attentional tradeoff*.

Our most recent MNC project (Vyazovska et al., 2014) studied the behavior of pigeons given a successive go/no go discrimination task involving four different dimensions of integral visual stimuli. Specifically, we trained nine birds to peck only 1 of 16 compound discriminative stimuli created from all possible combinations of two stimulus values from four separable visual dimensions: shape (circle/square), size (large/small), line orientation (horizontal/vertical), and brightness (dark/light). Some of the pigeons were assigned CLHD (circle, large, horizontal, dark) as the S+, whereas others were assigned SSVL (square, small, vertical, light) as the S+.

All of the pigeons acquired the MNC discrimination, indicating that they had attended to each of the four dimensions of the stimuli. In addition, the more dimensions along which the S−s differed from the S+, the faster was discrimination learning, suggesting an added benefit from increasing the number of perceptual disparities between the S−s and the S+. Finally, clear signs of attentional tradeoffs among the four dimensions arose during the course of discrimination learning, with marked upswings in discriminating one dimension accompanied by marked downswings in one or more other dimensions, particularly for pigeons taking longer to master the MNC discrimination.

Such attentional tradeoffs are believed to be the result of two basic and logically related aspects of attention (Pashler, 1998): *limited capacity* and *selectivity*. If an animal's attentional capacities are overloaded, then selectivity is a necessary consequence of limited capacity. The notion that paying more attention to some discriminative stimuli causes the loss of attention to others has been called the “inverse hypothesis” (Thomas, 1970).

The present project asked how replicable the results of the Vyazovska et al. (2014) study would be if the MNC task were given as a *simultaneous* discrimination rather than as a *successive* discrimination; indeed, *all* of our prior MNC investigations had used successive discrimination procedures. One might expect some disparity in performance because the simultaneous task allows the organism to directly compare the S+ with each of the S−s before deciding to which to respond, a possibility that is precluded in the successive discrimination, where only one stimulus at a time is presented and the organism must decide whether or not to respond to it. The inability to compare the S+ and S− compounds in the successive task might amplify any attentional and/or memory demands imposed by the MNC discrimination.

1. Method

1.1. Subjects

We studied 8 feral pigeons kept at 85% of their free-feeding weights by controlled daily feedings. The pigeons had served in unrelated studies prior to the present investigation and therefore needed no further pretraining before participating.

1.2. Apparatus

The experiment used four 36-cm × 36-cm × 41-cm operant conditioning chambers detailed by Gibson et al. (2004). The chambers were located in a dark room with continuous white noise. Each chamber was equipped with a 15-in. LCD monitor located behind an AccuTouch® resistive touchscreen (Elo TouchSystems, Fremont, CA). The portion of the screen that was viewable by the pigeons was 28.5 cm × 17 cm. Pecks to the touchscreen were processed by a serial controller board outside the chamber. A rotary dispenser delivered 45-mg pigeon food pellets through a vinyl tube into a Plexiglas cup located in the center of the rear wall opposite the touchscreen. Illumination during the experimental sessions was provided by a houselight mounted on the upper rear wall of the chamber. The pellet dispenser and houselight were controlled by a digital I/O interface board. Each chamber was controlled by an Apple® iMac® computer. The program that ran the experiment was developed in MatLab®.

1.3. Stimuli and experimental design

We prepared a total of 16 different integral shape/size/orientation/brightness compound visual stimuli created from two possible values along four dimensions (circle/square, large/small, horizontal line/vertical line, dark/light)—(paired S+ and S− stimuli are depicted in Fig. 1). The width/diameter of the large stimuli was 5.6 cm, whereas the width/diameter of the small stimuli was 3.8 cm. The RGB value of the dark stimuli was (110, 110, 110), whereas the RGB value of the light stimuli was (160, 160, 160).

We presented two compound stimuli on every training trial: an S+ and an S-, with the left-right positions of the two stimuli randomized across trials. The centers of the stimuli were placed 14.5 cm apart from each other, 6.5 cm from the edge, 5.0 cm from the top, and 9.0 cm from the bottom of the touchscreen area that was available to the pigeons. The discriminative stimuli were presented in the center of the touchscreen frame on a blue field (RGB values were 0, 0, 255) which filled the entire LCD display. The effective pecking area containing each discriminative stimulus (large or small) was 6.4 cm × 6.4 cm in order to equate the opportunity to record pecks from stimuli of both large and small sizes.