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INFORMATION PROCESSING DURING THE PRESOLUTION PERIOD: STIMULUS LOCATION EFFECTS IN DISCRIMINATION LEARNING

by

Cynthia Schupak

A dissertation submitted to the Graduate Faculty
in Psychology in partial fulfillment of the requirements
for the degree of Doctor of Philosophy,
The City University of New York

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5/1/02 — Sheila Chase
Date — Sheila Chase, Ph.D.

5/1/02
Date — Joseph Glick, Ph.D.

Advisory Committee:

Eric G. Heinemann, Ph.D., Hunter College, CUNY

Martin S. Chodorow, Ph.D., Hunter College, CUNY

Robert L. Thompson, Ph.D., Hunter College, CUNY

Bertram O. Ploog, Ph.D., College of Staten Island, CUNY

CITY UNIVERSITY OF NEW YORK

Abstract

Information Processing During the Presolution Period:
Stimulus Location Effects in Discrimination Learning

By

Cynthia Schupak

2002

Advisor: Professor Sheila Chase

The purpose of this research was to examine some of the processes through which organisms extract information from the environment. The experiments were designed to investigate what is learned by pigeons during training to visually discriminate between two forms, "x" and "◊", as a means for obtaining food. A two choice successive presentation procedure was used. The variables of interest were (1) the effects on acquisition time for the discrimination of these two forms following pretraining on a color discrimination task as well as the effects on acquisition time for the color discrimination following form pretraining; and (2) the effects of training the discrimination with the stimuli in a single fixed location compared to training with the stimuli in varying locations.

Experiment 1 provided evidence that the initial period of chance performance (the presolution period) is shortened for acquisition of a visual discrimination if it is preceded by discrimination training on an unrelated visual dimension. Birds required fewer trials to learn the form discrimination following

pretraining on the color discrimination, and fewer trials were required to learn the color discrimination following pretraining on the form discrimination.

Experiments 2, 3 and 4 were designed to determine whether the location of the discriminative stimuli on the display surface was a factor in acquisition time and performance. The length of the presolution period and asymptotic accuracy on the form discrimination was compared following training under two conditions: (1) with these stimuli presented only in a fixed visual location (the center of a 12.5-cm by 12.5-cm region of a touch screen on which pecks were sensed) and (2) with the stimuli presented in 17 different locations—including the center and four corners—within this "active area." Results of Experiment 2 confirmed the prediction that birds that were trained to discriminate between the two stimuli only in a single central location displayed a significant decrease in accuracy when these same stimuli appeared in the four corner locations of the active area, a distance of 6.4 cm from the training location. In order to determine whether or not the decrease in accuracy was due to failure to visually process stimuli in the untrained locations, a novel form, the outline of a rectangle, appeared in one of each of these locations at the same time as either the "x" or the "◊" appeared in the center location. It was expected that this novel form would disrupt performance for birds whose training had required them to "attend" to these and other locations, but would not interfere with the discrimination accuracy of birds whose training required that they attend only to stimuli in the center location. However, accuracy did not differ systematically under the two

conditions (Experiment 3), an effect that was found to be independent of the distance between the distracter and the discriminative stimuli (Experiment 4). It appears that, even with the discriminative stimuli appearing only in a single location, the birds did not ignore the remainder of the screen, an effect which appears to be attributable, in part, to the characteristics of the touch screen. Some birds met the requirement of producing a peck sensed by the touch screen by swiping it, others by pecking a region in which pecks were most likely to be sensed. In all instances, the birds' response behavior permitted a larger area of the screen to be processed than was expected.

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Stimulus Location Effects in Discrimination Learning

Interest in visual cognition in non-humans, as exemplified in Cook's (2001) cyberbook on avian visual cognition, has generated extensive research using complex visual stimuli such as colored photographs (Herrnstein, 1979; Vaughan & Greene, 1984), texture patterns (Cook, 1992; 2001), as well as displays composed of such complex elements as letters (Blough, 1985) or small pictures (Young & Wasserman, 2001). In these experiments pigeons are usually required to peck at the stimulus display prior to making a choice. For example, Young, Wasserman, and Garner (1985) investigated same-different categorization for simultaneously displayed arrays of small pictures as well as successively presented displays of these pictures. In the simultaneous version of the task, pigeons were required to peck 16 times anywhere on the 7-cm x 7-cm display. In the successive version of the task, a single peck at each item was required in order to produce the next item in the list.

Work on autoshaping (Brown & Jenkins, 1968) and on the "feature-positive effect" (Hearst & Jenkins, 1974) suggests that pigeons tend to peck the stimulus that is correlated with reinforcement. If this is so, is information processed only from the vicinity of the display to which pecks are directed? In the present experiments a touch screen was used to sense peck location without requiring pecks at a specific location. The area over which stimulus information was likely to be processed was examined by moving the stimuli to new locations and by presenting a novel (untrained) form at various distances from the discriminative stimulus. Training was given under two conditions: (1) with the discriminative stimuli presented in one location and (2) with these stimuli presented in various locations over a distance of 9 cm vertically and 9 cm horizontally.

A model of pattern recognition, such as the Natural Intelligence Model (NIM) proposed by Heinemann and Chase (Chase, 1983; Chase & Heinemann, 1983, 1989, 1991, 2001; Heinemann & Chase, 1990) must take into account what is learned when pigeons are trained to identify complex visual patterns. This model incorporates the assumption that it is during the presolution period (PSP), an initial phase of discrimination learning during which there is no evidence that the task is being learned, that a subject learns which stimulus events are "relevant". Heinemann (1997) tentatively suggested that pigeons learn to process visual stimuli only in the vicinity of the discriminative stimuli; that is, when trained on a visual discrimination task, a "sensory channel" is opened in the region in which the stimuli appear. Further, he suggested that learning where the stimuli will appear occurs during the PSP. If this channel is opened, for example, as the result of learning to discriminate between two colors, a new presolution period will not occur if forms replace colors as the discriminative stimuli. If pigeons do not attend to stimuli beyond this sensory channel, moving the stimuli to new locations outside the sensory channel should disrupt the discrimination. A correlate of this assumption is that presenting a novel form in a non-attended location should not disrupt performance.

The Presolution Period (PSP)

The continuity—noncontinuity controversy of the 1930s and 1940s (Lashley, 1942; McCulloch & Pratt, 1934; Spence, 1940; Kreshevsky, 1938) focused on whether or not learning about the discriminative stimuli occurs while performance is at chance. Continuity theorists considered learning to take place gradually from the beginning of training, while non-continuity theorists contended that learning occurred suddenly when a correct association was made and that training preceding this association was irrelevant to its formation. This controversy was never resolved (Goodrich, Ross & Wagner, 1961), though the location of a visual pattern appeared to determine whether continuity or noncontinuity results were obtained. This was demonstrated by Ehrenfreund (1948) in training rats on a pattern discrimination task, employing a reversal of S+ and S- reinforcement contingencies during the PSP. Ehrenfreud concluded that the differences in outcome obtained by continuity theorists (who found that reversals during the PSP retarded learning of the discrimination) and by noncontinuity theorists (who found that they did not) could be explained by changing the location of the pattern to a location in which it was most reliably fixated by the subjects. Under these circumstances, reversing reinforcement contingencies during the PSP resulted in retardation of discriminative learning, supporting continuity theory. This theory of gradual, cumulative learning that occurs during the PSP is fundamental to the present visual discrimination experiments.

In 1983, Heinemann's introduced a model based on a modification of Wald's (1947) sequential probability ratio test that provides an account of what is learned during the PSP for a sound intensity discrimination. According to Wald,

an optimal statistical model for determining whether two events differ significantly is the application of sequential tests as information is accumulated (e.g., as stimuli to be discriminated are presented to an observer), until a reliable difference between the two events is found. The number of tests required, in this context the length of the PSP, is a function of the difference in the distributions of sensations produced by the discriminative stimuli. The sensations associated with large differences between two discriminative stimuli require fewer presentations for detection than small differences, as would be expected if one makes a statistical test for the difference between two means. Therefore the length of the PSP is inversely related to the difference in discriminability of the stimuli. If some larger stimulus differences are experienced during the PSP for a difficult discrimination the length of the PSP is shortened.

The relation between stimulus discriminability and the length of the PSP was demonstrated in an experiment by Heinemann (1983), the results of which are shown in Figure 1. In a two choice procedure, one of two stimulus values from a continuum (levels of white noise intensity) was presented on each trial. Two illuminated circular pecking keys in different locations also were presented on each trial. The pigeon's behavior was reinforced for pecking one

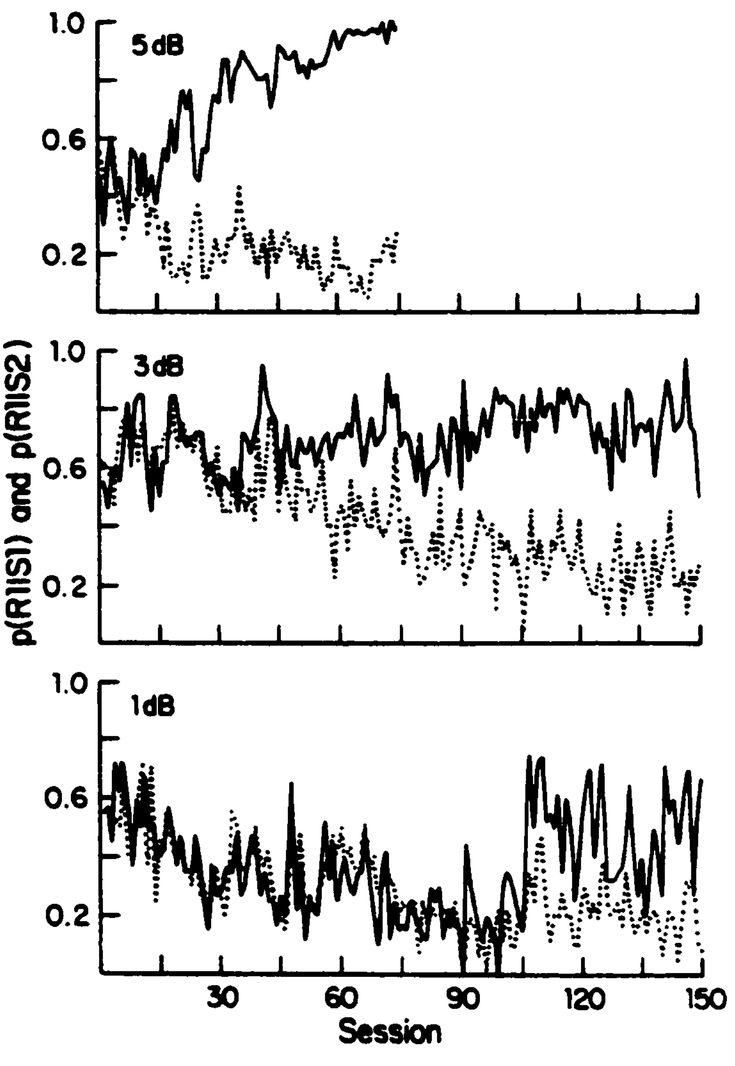

Figure 1. Each panel shows the proportion of R_1 responses made in the presence of S_1 (solid line) and in the presence of S_2 (dashed line) for a single pigeon. Training is plotted against 80-trial sessions (from Heinemann, 1983).

key in the presence of one stimulus intensity and the other key in the presence of the other stimulus intensity. This figure shows the proportion of correct ("hits") and incorrect ("false alarms") key choices made by three pigeons, one trained to discriminate between sound intensities differing by 5 dB, one by 3 dB and one by 1 dB as a function of sessions of training. The PSPs are visible in this figure as the initial portions of the two curves that co-vary or overlap, demonstrating chance responding. The end of the PSP may be treated as the section wherein the two curves begin to separate reliably. An increase in discriminability resulted in a decrease of the PSP duration.

As predicted by the sequential probability ratio test, training on easier tasks on the same perceptual dimension (intradimensional training) during the PSP facilitates acquisition of a more difficult discrimination. For example, Knopp (1980) demonstrated that the length of the PSP for an auditory stimulus discrimination was shortened when pigeons who were being trained on a 5-dB sound intensity difference were given some trials with a larger intensity difference of 30 dB during the PSP. Pavlov (1927) noted that subjects given prior training on a series of easier brightness tasks required fewer trials to learn a difficult brightness discrimination than those that did not receive such training. Lawrence (1952) determined that experience with a single easy discrimination could be as effective as a series of gradual shifts in producing more efficient acquisition of a difficult discrimination. The facilitative effects due to prior easy training have come to be known as the "easy-to-hard" effect and "transfer along a continuum."

Pretraining on an extradimensional task has also been found to influence subsequent acquisition. In Heinemann's laboratory a color cue is routinely used in training birds to discriminate between two simple patterns or forms. For example, Donis and Heinemann (1993) initially presented one of the forms to be discriminated in red, and the other form in white. The presentation of each form was differentially reinforced contingent upon a peck to one of two simultaneously presented choice keys. When discrimination accuracy reached 80% the color cue was eliminated. The effects of this procedure have not been formally examined prior to the present experiment. .

Evidence for facilitation of a discrimination by pretraining on an extradimensional task was obtained by Terrace (1963). In examining errorless learning, Terrace initially trained pigeons to peck a key when a red light was presented on it (making the color red a positive or reinforced stimulus, S+), and not to peck the same key when a green light was presented on it (making the color green a negative or nonreinforced stimulus, S-). Terrace compared three methods of transferring this discrimination to a vertical and horizontal line discrimination: an abrupt replacement of the S+ and S- colors with vertical and horizontal lines; a superimposition of the line stimuli on the key at the same time as the color stimuli; and a superimposition of the line and color stimuli in which the line was faded in (increased in intensity) gradually as the colors were faded out (reduced in intensity). Terrace found these methods to facilitate (shorten learning time or reduce errors) during acquisition of the line orientation discrimination when compared with a "trial and error" procedure in which the line orientation discrimination was not preceded by, or correlated with, a color discrimination. Because the color and the line stimuli were presented on the same pecking key, this facilitation may be attributable to the opening of a sensory channel at this location during the PSP, thus demonstrating a "location effect" as defined here.

Seraganian (1979) investigated pigeons' acquisition of a difficult grating orientation discrimination under several different pretraining conditions as compared to training on the grating discrimination only. Two of these conditions used color as an extradimensional cue. In one condition, the gratings to be discriminated were presented on a response key which also lit up with an orange color during S+ (stimulus to which pecks were reinforced) presentations and an amber color on S- (stimulus to which pecks were not reinforced) presentations. In another condition these two colors were presented for discrimination without the grating. Both these pretraining conditions, as well as an easier intradimensional grating orientation condition, were found to shorten acquisition time for the difficult discrimination. The two color pretraining procedures constituted abrupt rather than gradual, faded transfer from one discrimination to another. Seraganian concluded that "discrimination acquisition appears sufficient to alter the rate at which subsequent discriminations are acquired" (p. 52).

This statement is compatible with a "general attentiveness" model of learning which presumes that a general learning capability is acquired by a subject through discrimination training, and that this general attentiveness facilitates acquisition in subsequent discrimination tasks involving other stimulus dimensions. Frieman and Goyette (1973) pretrained pigeons to peck a response key illuminated with either a single color stimulus or two different colored stimuli presented successively, then transferred the two groups to an auditory discrimination task with a ring-pulling response. The two-color discrimination group learned the second task faster than the group with single-color training. The authors concluded that during discrimination training, "*S* learns to pay attention to nonspecific stimulus differences, and that attention is the factor that mediates transfer... [showing] the applicability and utility of a general attention explanation of transfer by extending the concept to situations involving different stimulus modalities and response classes" (p. 240). These results are consistent with the assumption underlying the present study that pretraining on extradimensional, as well as intradimensional, tasks can facilitate learning on subsequent tasks through attentional operations that take place during the PSP.

Ploog and Williams (1995) pretrained pigeons to discriminate between two colors prior to training a difficult ("target") discrimination of two vertical white lines that flickered on and off and differed only in the period during which the line was visible. The stimuli were presented on two pecking keys displaced in horizontal location, one on the right and one on the left of a blank central key. All 12 pigeons were pretrained initially on a simultaneous blue and yellow color discrimination using a procedure in which a peck at S+ (the blue or yellow key light) was reinforced while a peck at S- (the other colored key light) terminated the trial and was not reinforced. Following this pretraining, a "trial-and-error" group was trained only on the flicker discrimination. These pigeons functioned as a control group to be compared with groups trained on other methods that followed color pretraining. The first of these methods was an easy flicker-rate discrimination that was gradually increased in difficulty until it equaled the target discrimination. This procedure facilitated transfer to the difficult flicker discrimination relative to the group given trial-and-error training. The second method was a "fading procedure" in which the target flicker discrimination was presented on the key lights at the same time as the two pretrained colors were, and the blue and yellow color cues were gradually faded out. Although it produced the fewest errors when the colors were present, this fading procedure did not facilitate learning of the target discrimination compared with the trial-and-error group. When tested periodically without the color during training, the birds trained with the fading procedure showed acquisition curves very similar to those of the trial-and-error group.

Placing the discriminative stimuli directly on the response keys has been a common practice, but it is not the only way to train pigeons to discriminate among visual stimuli. Newman and Benefield (1968) used a procedure in which birds learned to peck at a blank key which produced the discriminative stimuli on a screen for 3 s, simultaneously with the operation of the food magazine. Thus, the birds' behavior controlled the production of the discriminative stimuli, and the off-the-key stimulus display acquired signaling properties for reinforcement.

The present work also used off-the-key stimuli and did not require direct pecks at the stimuli themselves. In Experiment 1 the pretraining stimuli were red and green rectangles, two colors used frequently as choice stimuli in matching-to-sample experiments, and that are known to be highly discriminable for pigeons (Wright & Cumming, 1971). It was expected that the length of the PSP necessary for birds to acquire the "x" and "◊" form discrimination would be longer than that required to learn the color discrimination, and that pretraining the color discrimination would facilitate the acquisition of the form discrimination by reducing the length of the PSP. It was of interest also to determine whether training on the more difficult form discrimination would shorten the PSP for color.

Location Effects

Heinemann (1997) suggested that pigeons only attend to those visual locations that have passed through the PSP. Several experiments carried out by Heinemann and his colleagues have examined the effects of shifting (translating) an object to a physical location different from the one in which the pigeon was trained to recognize it. Heinemann and Kadison (1976) trained pigeons to peck an evenly illuminated center key which, on random trials, displayed a central circular area of brighter light. A peck to this stimulus key produced the illumination of two side keys, one of which was correct when the stimulus key contained the bright central "spot", and one of which was correct when this bright spot was not present. The luminance and position of the spot were then varied during a generalization test. The pigeons' discrimination between presence and absence of the spot was essentially perfect when it was located in the center of the disk. For most of the other test positions, however, the birds behaved almost as though the spot did not exist.

Similar results were obtained in several unpublished pilot experiments by Chase on pattern identification. In one of these, three pigeons were trained to identify each of four shapes by pecking on one of four different response keys. These patterns were always presented near the center of the 6-cm square face of a small monochrome TV monitor. During a location test that followed training, probe trials were interspersed among training trials. On each probe trial one of the four shapes was presented 3 cm above and to the right of the training position. During this test the birds averaged 72% correct when the stimuli were in their training position, but only 31% correct when the stimuli were in the new position. Two of the three birds actually performed at chance (25% correct) with the stimuli in the new position. These results suggest that even small changes in the position of visual patterns can cause recognition of these patterns to deteriorate. However, it is important to note that these effects (i.e., errors when position changed during testing) occur when the pattern is always in the same position during training, and other visual cues are present. If the pattern is moved around during training, pigeons may learn to search for it. In this and the present experiments the effects of the location of the stimuli, as represented by the Fixed and Variable training conditions, were examined.

In these, and in most experiments on visual discrimination learning, the retinal location of the stimuli is not fixed. However, because the stimuli generally are either displayed on the pecking key, or the birds are required to peck at the discriminative stimuli prior to making a choice, the stimuli probably are seen in frontal vision. In the present experiments the pigeons were not required to peck at the discriminative stimuli. A peck anywhere within a 12.5-cm by 12.5-cm region of the touch screen was sufficient. It is of interest to note whether, under these conditions, the pigeons will peck at the stimuli and thus see them in frontal vision. Work on the feature-positive effect (Hearst & Jenkins, 1974) suggests that this occurs. If they learn to search for the stimuli, the discrimination should not be affected by changes in location.

In an attempt to discover what pigeons learn about stimulus location in a situation in which both the physical location and the retinal position of the stimuli were fixed, Yamashita (1991) initially trained pigeons to peck (for food reinforcement) at a central "fixation" target when an "x" (S+) was presented but not in its absence (S-). Following this detection training, a discrimination task was implemented (Experiment 1). During this task the birds were required to discriminate between the S+ ("x") form and an S- ("o") form when each were presented at different horizontal locations from the training location. Figure 2 shows the accuracy results obtained for a bird trained with the stimuli in a central position when tested for generalization to new locations. Yamashita found that although the pigeons failed to demonstrate discrimination between the training stimuli when these were first shown in new positions, after extensive training all birds learned to discriminate between them in positions covering a horizontal range of over 8.8 cm. The horizontal range over which location effects were examined in the present experiments was similar to that used by Yamashita.

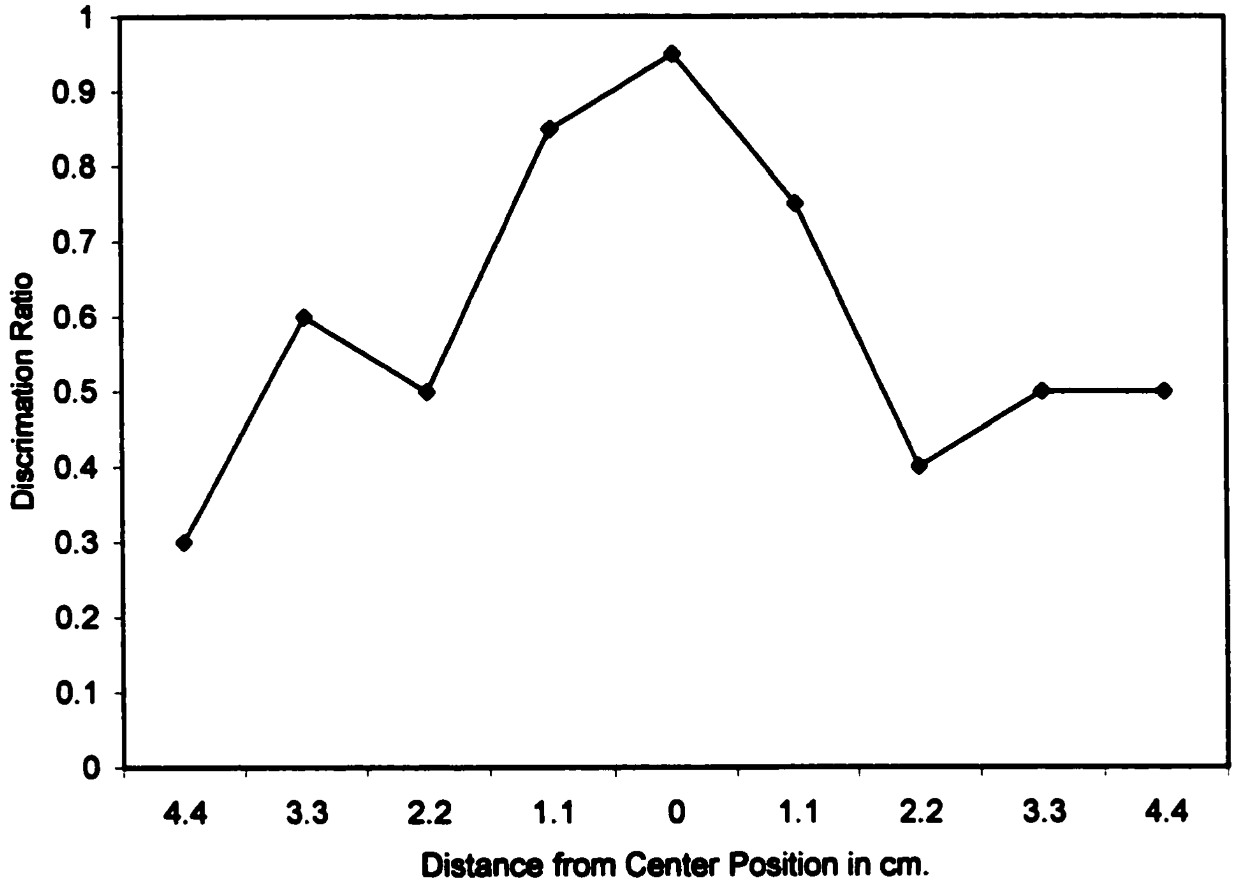

Figure 2. Generalization gradient for recognition of the discriminative stimuli displaced in lateral distance from the central (0) training location (after Yamashita, 1991).

Distracter Effects

The "distracter effect" refers to the impairment of an acquired discrimination between two visual stimuli by the addition to the display of a visual feature that is not correlated with response choice. Donis and Heinemann (1993) trained pigeons to discriminate between diagonal lines presented alone or embedded in a redundant L-shaped right-angle form. Eleven out of 12 birds were consistently more accurate when the diagonal lines were presented alone than when embedded in the L-form. Donis, Heinemann and Chase (1994) showed that the degree of interference with the discrimination increased with decreasing distance of the redundant form from the discriminative stimuli.

The addition of a novel visual feature to the spatial display area after acquisition of a form discrimination is of importance in testing the notion that the location of a stimulus is a dimension that is visually processed, along with other relevant stimulus attributes, during the PSP. Thus, it can be said that the location itself has passed through the PSP during stimulus discrimination training. If a novel visual feature is presented outside such a spatial region it should not be processed, and should not distract from the accuracy of the discrimination. However, if it is presented in a spatial location within which stimuli have been processed, the distracter is expected to interfere with identification of the discriminative stimuli.

Thus, introduction of a distracter within a region in which the stimuli previously never appeared should not interfere with the discrimination. The discrimination should remain intact. In contrast, a distracter placed in the same region of the visual display in which the discriminative stimuli appeared during training should interfere with the discrimination. In this way, the effects of a distracter on the accuracy of a trained discrimination may serve as a means of determining which areas of the visual display are processed. It was hypothesized that a distracter would disrupt discrimination performance only if it occurred within the region attended to, that is, the region that has passed through the PSP.

General Methods

Subjects

The subjects were ten experimentally naive White Carneaux pigeons (*Columba livia*), about one year old at the start of the experiment, of unspecified sex, and purchased from Double-T Farms, Glenwood, Iowa. They were housed individually in cages in an auxiliary unit of the Animal Care Facility, under an 11-13 light-dark cycle. They were transported to another room for training. The pigeons were maintained at 80% to 85% of their free-feeding weights during the experiment and had unlimited access to water and grit in their home cages. During training and testing, the birds received supplemental feedings of Purina Gold pigeon pellets with the amount adjusted to maintain them at their experimental weights.

Apparatus

Training and testing was conducted in two virtually identical operant chambers. Each of the chambers consisted of two compartments with interiors painted flat black. The pigeons were trained in the smaller compartment, the interior of which measured 50.5 cm high by 45 cm wide by 32.5 cm long. One wall of this chamber contained a 21.5-cm high by 27.5-cm wide transparent touch screen (Elographics, Model E274). The touch screen was used to monitor the occurrence and the position of pecks on this surface. The stimuli were displayed on a 14-inch computer monitor (Gateway, Model 220) that was placed directly behind the touch screen in the larger of the two compartments. Ventilation fans cooled the chambers and provided masking noise. Each chamber had two pellet dispensers programmed to deliver food pellets (formula C1, 45-mg; P.G. Noyes Co.) into two cups, one at the lower right and one at the lower left of the panel containing the touch screen. Delivery of a single pellet was preceded by a 1.5- to 2-second sound produced by the dispenser motor[1]. Dim ambient illumination was provided by a 4-watt house light bulb which was located in the ceiling of the chamber.

Preliminary training.

The pigeons were first shaped by reinforcing successive approximations to peck on the lower left hand or right hand corner of the touch screen. Pecks or beak strokes to these corner regions activated the touch screen only when two light gray 150-cd/m^2 2-cm disks (subtending a visual angle of 28.6° at a viewing distance of 55 mm, the F2 position described by Goodale, 1983) were presented in these positions on the otherwise unilluminated monitor. These touch screen regions comprised areas of approximately 6 cm from the bottom and 6 cm from the lower left and right sides of the touch screen, and were sensitized to register and record effectively strong pecks or beak strokes only when the gray disks were illuminated on the monitor behind them. These regions, when they were sensitized, will be referred to as "choice keys", although they are not, in fact, actual mechanical pecking keys. Pecks or beak strokes sensed by the screen in the lower left choice key region will hereafter be referred to as R_1 responses; those in the lower right choice key region as R_2 responses.

It is of interest to note that the pigeons' behavior during training and testing rarely included actual ballistic pecks directed at the stimuli, the active regions, or the choice keys. In general, all ten pigeons' responses to the display areas of the screen took the form of varying numbers and extents of stroking or swiping movements with the beak. When these responses were directed to the choice key regions, they tended to be somewhat more restricted in the range of beak movements, and most consisted of open-beaked strokes combined with light pecks. To simplify description, any effective beak response or responses to the display or choice key regions of sufficient intensity to be sensed by the touch screen will be referred to as a "peck".

During the initial shaping procedure, only one choice key disk was illuminated. Pecks to this choice key were followed by the sound of the feeder motor and delivery of a food pellet into the cup adjacent to that key. Trials were separated by an intertrial interval (ITI) during which neither choice key disk was illuminated and pecks had no scheduled consequences. When the birds readily pecked one choice key, the other choice key was illuminated, and they were trained to peck this key.

After the birds reliably pecked whichever choice key was illuminated, they were trained to peck within a 12.5-cm by 12.5-cm central region of the touch screen, the "active area", in order to produce choice key illumination. This active area extended from the top of the touch screen to approximately 9 cm from the bottom and 7.5 cm from the left and the right edges of the touch screen. In order to shape pecking within this region a rectangle or a disk, approximately the size of a choice key disk, was displayed within the active area. A peck anywhere within this area was followed by illumination of one of the choice keys. A peck at this choice key was followed by delivery of a food pellet. The 17 locations in which stimuli were presented as well as the location of the choice key disks, as described above, are illustrated in Figure 3. The sequence of events in preliminary training are detailed in Appendices A and B.

Discriminative Stimuli

The stimuli used in the discrimination tasks are illustrated in Figure 3. For training on the form discrimination an R_1 (left choice key peck) was defined as correct when an "x" appeared on the monitor and an R_2 (right choice key peck) was correct when a "◊ " was shown. These forms were composed of eight pixels and were achromatic (luminance =195 cd/m^2) on the darkened computer monitor. The forms were 8 mm high and 4 mm wide subtending a visual angle of 8.28° vertical by 4.16° horizontal if viewed at 55 mm (the F2 position). For training on the color discrimination the discriminative stimuli were a "red" and a "green" filled rectangle 8 mm high and 4 mm wide. R_1 was correct when the rectangle was red, and R_2 was correct when it was green.

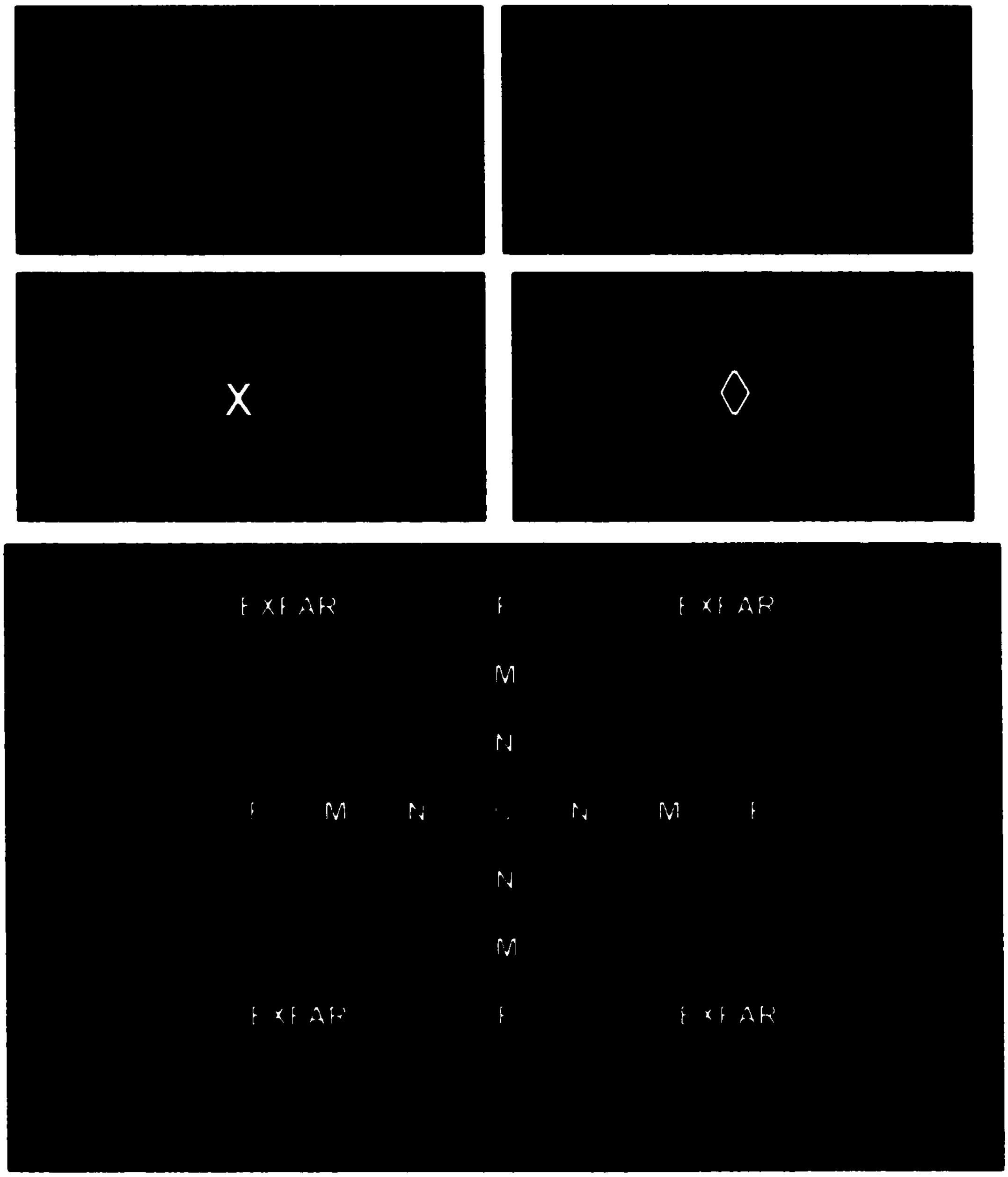

Figure 3. Display screen illustrations (not to scale).
Upper panels: "red" and "green" color, and "x" and "◊" form stimuli.
Lower panel: 17 stimulus locations, and R_1, R_2 choice key disks.

Training conditions

Five of the birds were trained with the stimuli in only a single position (Fixed Condition). For five other birds, stimuli could appear in any one of 17 different positions (Variable Condition). The range over which the stimuli were displayed during trials in this condition subtended visual angles of 66° by 66° when viewed at a distance of 55 mm. For the birds trained under the Fixed Condition the red or green rectangles or the achromatic "x" and "◊" forms appeared only in the center (C) location of the active area of the display surface. Under the Variable Condition, the red and green rectangles or the "x" and "◊" forms each appeared in one of 17 different locations within the active region of the screen: the center (C), four near (N), four medium (M), four far (F) and four extra far (EXFAR) positions (see Figure 3).

Assignment to Conditions

The assignment to conditions for Experiment 1 is shown in Figure 4. Four of the birds were trained initially with the red and green rectangles, two under the Fixed Condition and two under the Variable Condition. Six were trained initially on the form discrimination, three with the forms only in a fixed position (FF for Form Fixed) and three with the forms appearing on separate trials in one of the 17 positions (FV for Form Variable). Five of the six birds trained initially on the form discrimination successfully transferred to the color discrimination.

Bird / Code	Stimulus Location Condition	Discrimination Pretraining	Discrimination Transfer Training	Location/Dist Tests
1 C-FF1	Fixed	Color	Form	Yes
2 C-FF2	Fixed	Color	Form	Yes
3 C-FV1	Variable	Color	Form	Yes
4 C-FV2	Variable	Color	No Transfer	No
5 FF1	Fixed	Form	Color	Yes
6 FF2	Fixed	Form	Color	Yes
7 FF3	Fixed	Form	No Transfer	Yes
8 FV1	Variable	Form	Color	Yes
9 FV2	Variable	Form	Color	Yes
10 FV3	Variable	Form	Color	Yes

Figure 4. Assignment of all ten pigeons to training and test conditions.

Discrimination Training

Discrimination training differed from the final stage of preliminary training mainly in that, following a peck within the stimulus display region, both choice keys were illuminated simultaneously. The birds received a food pellet for a peck at the key designated as correct for the given stimulus on a continuous reinforcement schedule. The trial began with the darkening of the screen to 2-cd/m^2 and the simultaneous appearance of a red or green rectangle or the "x" or "◊" form on the dark screen in either the central position, or one of the 17 locations. A peck anywhere within the active region simultaneously ended the presentation of the stimulus and illuminated both choice keys. A peck at the correct choice key resulted in delivery of food, and an increase in the luminance of the screen to a light gray (14 cd/m^2) which remained so for the 4-s ITI during which pecking had no programmed consequences. Following an error, the screen darkened to 2 cd/m^2 for 4.5 seconds, and this was followed by the 4-s ITI. The same stimulus was presented again. On this second (correction) trial, a peck within the active area resulted in the illumination of only the correct choice key, and as a result few errors were made. Only choices made on the first presentation of the stimulus on each trial were used in data analysis.

Under the Fixed Condition the two stimuli were presented in the center position 68 times each. Under the Variable Condition the two stimuli were presented in each of the 17 positions four times during each session. Thus, a session consisted of 136 trials. Within these constraints, the stimuli were presented in random order.

Experiment 1.

Will Acquisition of a Color Discrimination Facilitate Acquisition of a Form Discrimination and Vice Versa?

The first experiment focused on the possible influence of pretraining to discriminate between two colors or two forms on the length of the PSP for the alternate dimension. According to Heinemann (1997), during the PSP the pigeon learns about the spatial location in which the discriminative stimuli appear. If discrimination training opens a "sensory channel" in this region, pretraining with form or color should decrease the length of the PSP for the alternate dimension.

Method

Subjects. The ten pigeons who participated in this experiment are described above.

Apparatus. The apparatus was as described above.

Procedure. The birds were trained under their assigned conditions. Four pigeons were trained to discriminate between the two colors prior to training to discriminate between the two forms. Six pigeons were trained from the start on the form discrimination. Form training in the Fixed Condition is coded as FF (Form Fixed). Form training in the Variable Condition is coded as FV (Form Variable). The letter C precedes these codes for birds trained first on color, C-FF and C-FV.

All birds were trained for 75 days (one session of 136 trials per day) on the form discrimination. Following this, all birds received 15 days of training during which the reinforcement schedule was reduced to 80% by the addition of 32 extinction trials, for a total of 168 per session.

For the four birds trained under the C-FF and C-FV Conditions this form discrimination training was preceded by 30 days of training on the color discrimination. For the C-FF birds the colors were shown only in the central position. For the C-FV birds the colors were shown in each of the 17 positions. Ninety days after the training was completed, five of the six (FF and FV) birds who had been trained only on the form discrimination were given ten sessions of retraining on form followed by training for the first time on the color discrimination. One bird, FF3 would not respond when reintroduced to the form discrimination task and therefore was not given this additional training.

Results and Discussion

With the exception of one bird, C-FV2 , all birds acquired the form discrimination and that performance was asymptotic, or nearly so, by the end of training under all conditions. Figure 5 shows the proportion of R_1 responses plotted against sessions for the birds trained under conditions FF and FV. R_1 responses in the presence of S_1 (hits) are the solid lines and R_1 responses in the presence of S_2 (false alarms) are the dashed lines. Figure 6 shows these data for the birds trained under conditions C-FF and C-FV. This way of plotting the data shows both increases in correct responses and decreases in incorrect responses as the discrimination is acquired. This is important in assessing key position preference (bias) separately from sensitivity to stimulus differences (*d'*). As long as these two curves overlap or co-vary, it is assumed that the bird has

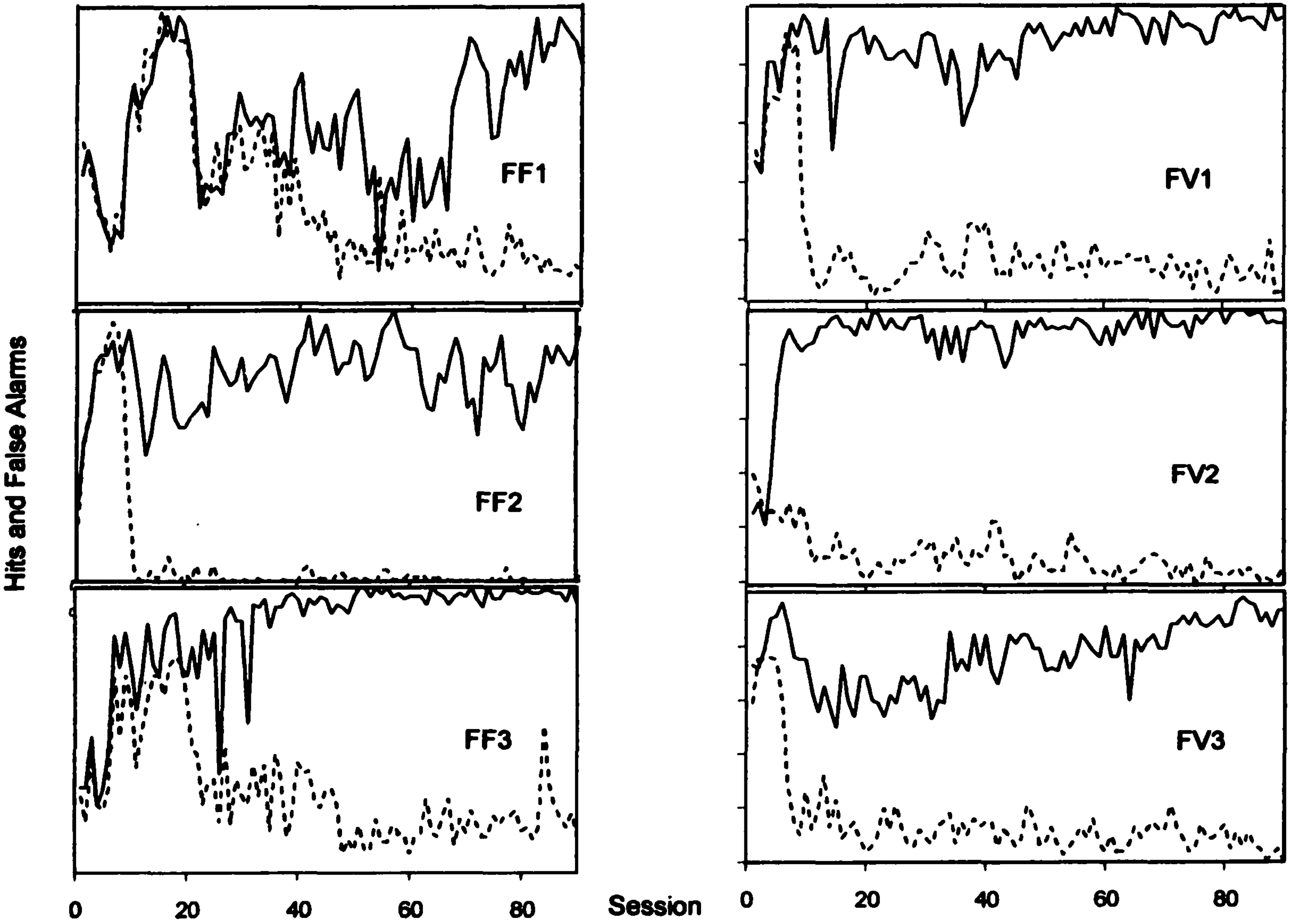

Figure 5. Proportion of Hits (solid lines) and False Alarms (dashed lines) for the six birds trained initially on form.

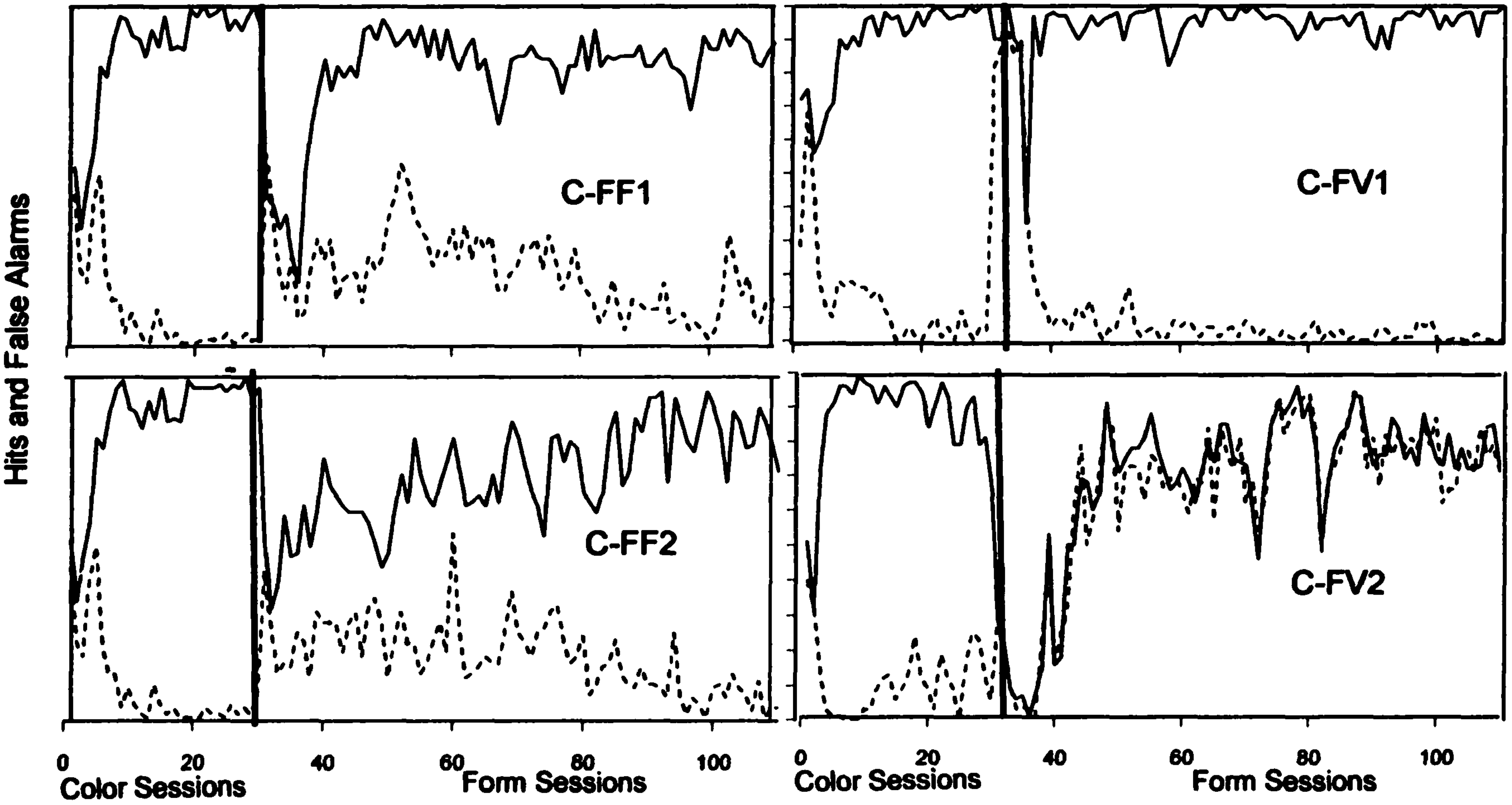

Figure 6. Proportions of Hits (solid lines) and False Alarms (dashed lines) for the four birds pretrained on color.

not emerged from the PSP. This is evident in the case of Bird C-FV2 (Figure 7) during the form training portion of the plot. Acquisition of the discrimination is marked by gradually increasing separation of the curves for correct and incorrect responses. The plots for the pretrained birds (Figure 6) show graphically the rapid separation of the hits and false alarms curves during color discrimination training (i.e., short PSPs) and the large degree of separation between the two curves (high *d'* values) compared with the more gradual and lesser degrees of separation of the curves during form discrimination training in the pretrained as well as non-pretained birds (Figures 5 and 6). These data were used to examine the effects of pretraining with the color stimuli on the length of the PSP for the form discrimination. In order to obtain a quantitative estimate of the length of the PSP, the 136-trial sessions were divided into eight blocks of 17 trials each. The first block in which the proportion of correct responses reached .75 or above was taken as the end of the PSP for that bird, provided that there was at least one other block of .75 or greater within that session and no blocks with proportions at chance.[2]

Table 1 is a summary of the estimated lengths of the PSPs for the birds that were trained to discriminate between the two colors followed by training to discriminate between the two forms (Conditions C-FF and C-FV), and for those trained on the form discrimination followed by training on the color discrimination (FF and FV). The PSP for form is omitted for the bird (C-FV2) whose form discrimination remained at chance throughout the 90 sessions of training (see Figure 5).[3]

Table 1. All birds' comparative PSP lengths for color and form acquisition using proportion of correct responses for each block of 17 trials.

		PSP Lengths (In Blocks)		
Condition / Bird		Phase 1 Color Training	Phase 2 Form Training	Phase 3 Color Training
Fixed	FF1	--	317	9
Fixed	FF2	--	74	2
Fixed	FF3	--	144	N/A
Variable	FV1	--	65	2
Variable	FV2	--	35	9
Variable	FV3	--	46	6
		Means:	113.5	5.6
Fixed	C-FF1	5	26	--
Fixed	C-FF2	17	20	--
Variable	C-FV1	27	41	--
Variable	C-FV2	19	N/A	--
	Means:	17	29	

Form training reduced mean PSP length for color: 17 vs. 5.6

Color training reduced mean PSP length for form: 113.5 vs. 29

The three birds of four birds initially trained on color who transferred successfully to form showed a mean PSP for acquisition of the form discrimination of 29 blocks. For the birds who did not receive color pretraining, the mean for acquisition of the form discrimination was 113.3 blocks. Although the mean PSP for acquisition of the form discrimination following color pretraining was considerably shorter than that obtained for the birds who did not receive color pretraining, the difference was not statistically significant ($t(8) = 2.268$, $p > .05$). The mean PSP for the color discrimination for birds initially trained on this task was 17 blocks. The birds who had been trained only on the form discrimination acquired the color discrimination in an average of 5.6 blocks. For these birds, the PSP for color was significantly ($t(7) = 2.371$, $p < .05$) shorter than that for the birds who were not pretrained on form. Thus, pretraining on the color discrimination shortened the PSP for form (though not significantly), and pretraining on the form discrimination shortened the PSP for color (significantly). This finding suggests that learning is, at least partially, independent of the dimension of the stimuli used in discrimination training. This is compatible with Heinemann's notion that the birds learn where the discriminative stimuli appear during the PSP; that is, a "sensory channel" is opened in this location. If this is so, it follows that stimuli appearing within the training location will be identified more accurately than they would be if the appeared in other locations. This experiment also provided supportive evidence for Heinemann's (1983) proposal that there should be an inverse relation between PSP length and *d'* at asymptote. PSP length and *d'* at asymptote were computed and examined for the six birds who acquired the form discrimination without having undergone color pretraining. These measures are arranged in order of shortest to longest PSP lengths along with concomitant *d'* values in Table 2. As predicted, the correlation coefficient was negative ($r = -0.716$).

Experiment 2.

Location Effects in Training and Generalization

Experiment 1 addressed the effects of different ordering of extradimensional training conditions on the length of the PSP. The purpose of Experiment 2 was to focus on two other questions basic to the understanding of the processing of visual stimuli by pigeons: (1) the effects on the acquisition of a discrimination if the stimuli to be identified appear in one, as opposed to many, locations and (2) the extent to which training to discriminate between two visual stimuli in a fixed location generalizes to novel (untrained) locations. In order to address these questions, the discrimination performance of the pigeons trained with the stimuli in a fixed location was compared with that of pigeons trained with the stimuli appearing in 17 different locations. To determine if the location of the stimuli might influence discrimination performance, training was followed by a generalization test in which these stimuli were shown in the four EXFAR locations (see Figure 3).

Pigeons who did not previously experience these stimuli in the EXFAR locations were expected to show a decrement in performance if a "sensory channel" is opened only in the vicinity of the training location. Such a decrement in performance is referred to here as a "location effect." Those who

Table 2. Relationship between PSP length and *d'* at asymptote.

BIRDS TRAINED ON FORM ONLY:

Bird	*d'*	PSP length	
		Blocks	Trials
FV2	4.5	35	280
FV3	3.1	46	368
FV1	3.2	65	5200
FF2	3.6	74	5920
FF3	3.0	144	11,500
FF1	2.5	317	25,360
Means:	3.32	113.5	8104.7

Correlation coefficient: $r = -0.716$

were trained on some trials with the stimuli in the EXFAR positions were expected to continue to perform as they did during training.

Ideally, these location experiments would have been conducted with birds whose training histories were identical. Unfortunately, the small number of birds available did not allow division into groups based on training sequence.

Method

Subjects. The subjects were the nine pigeons who acquired the Form discrimination.

Apparatus. The apparatus was the same as that used in Experiment 1.

Procedure. Procedures used in training the discrimination are described under Experiment 1. As described in Experiment 1, after each bird exceeded 85% correct on the form discrimination (75 days of training) the proportion of reinforced correct responses was reduced by 20%. For this purpose, an additional 34 non-reinforced, or extinction trials (17 on which the "x" was presented and 17 on which the "◊ " was presented), were randomly interspersed among regular training trails for 15 sessions. On these additional non-reinforced trials, or probe trials, all choices were followed only by the ITI and then the next programmed stimulus.

Following these 15 partial reinforcement sessions, tests for generalization to new locations were initiated. This was done by presenting, on 16 probe trials, the "x" or the "◊" twice in each of the four EXFAR positions during each test session. (Test sessions also included 16 probe trials in which an added novel form appeared in the EXFAR position, the data from which will be discussed under Experiment 3). Three such test sessions were given on three consecutive days.

Results and Discussion

Figure 7 compares the average proportion correct for the (non-pretrained) FV and FF birds during form discrimination training. For these two groups, accuracy was higher under the FV Condition than under the FF Condition essentially throughout training. In order to further compare the difference in the effects of training under the FV and the FF conditions the PSP lengths, proportion correct and *d'* during the final 24 sessions was obtained (see Table 3). Although, for all three measures the FV birds performed better, only the difference in proportion correct was significant, $t(4) = 3.35$, $p < .05$.

It appears that training with the stimuli in a fixed location is not as effective as training with the stimuli in variable locations. Observation of the birds' peck locations suggests that under the Variable Condition the birds tended to peck more directly at the stimulus. Under the Fixed Condition they tended to peck to the left or right of the stimulus—to the left if the left choice key was chosen, to the right if the right choice key was chosen. If the form was consistently viewed in the central portion of the frontal visual filed, it may have been seen more clearly by the FV birds. Also, the pattern to be identified would be more similar to remembered patterns if the forms were consistently viewed in the same area of the visual field.

Table 4 shows the proportions correct for the location test. The data for the bird who did not acquire the discrimination is excluded from the analyses.

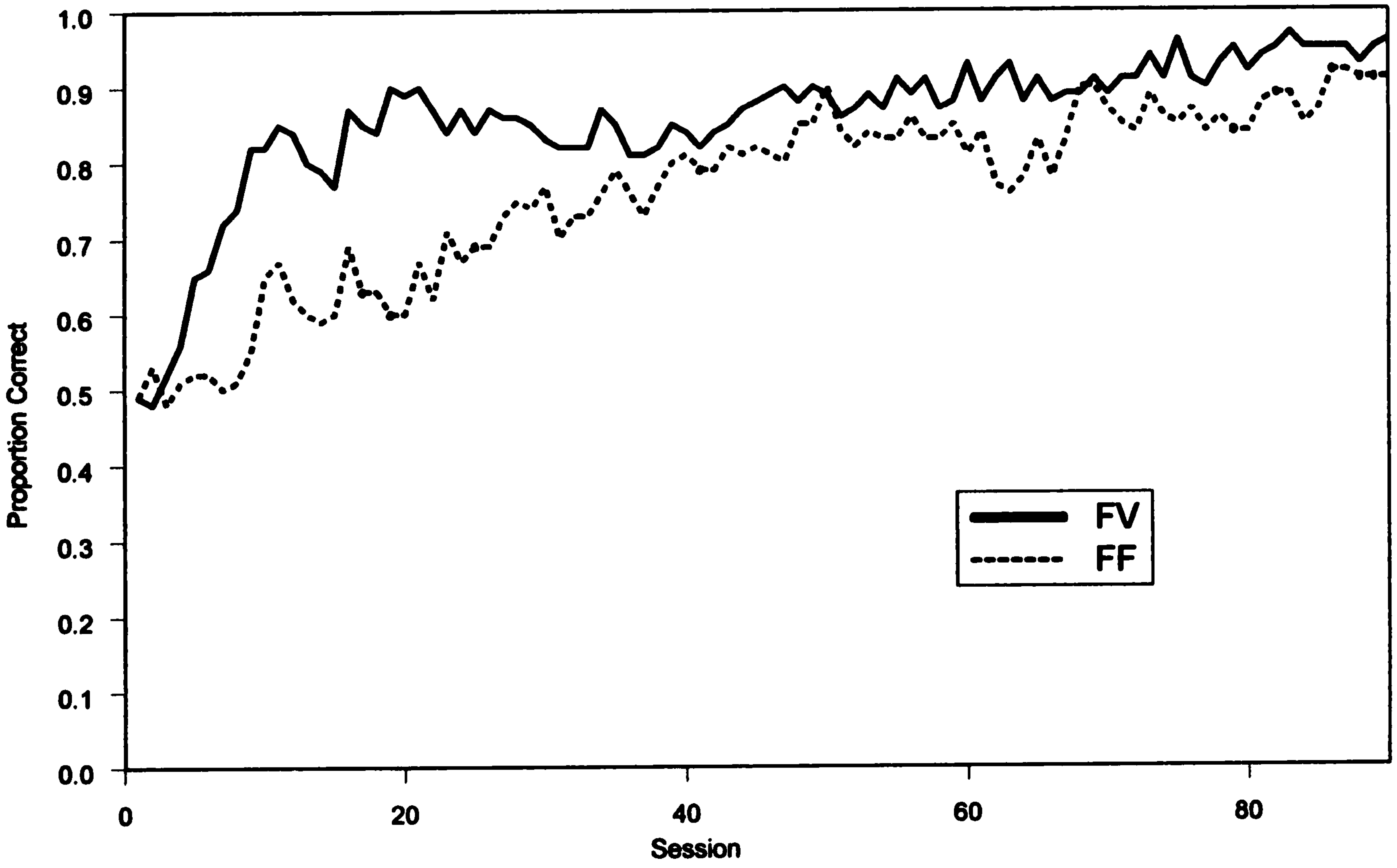

Figure 7. Mean proportion correct plotted against training sessions for the three FF birds and the three FV birds.

Table 3. Asymptotic *d'*, proportion correct and PSP length for all birds according to training condition.

BIRDS PRETRAINED ON COLOR:

Bird	*d'*	Proportion Correct	Length of PSP	
FF-FV Birds:			Blocks	Trials
C-FF1	2.7	87.1	26	442
C-FF2	2.6	90.3	20	340
C-FV1	4.8	96.7	41	697
Means:	3.37	91.4	29	493

BIRDS NOT PRETRAINED ON COLOR:

Bird	*d'*	Proportion Correct	Length of PSP	
FV Birds:			Blocks	Trials
FV2	4.5	96.8	35	280
FV3	3.1	91.4	46	368
FV1	3.2	93.0	65	5200
Means:	3.6	93.7	48.7	1949
FF Birds:				
FF2	3.6	86.5	74	5920
FF3	3.0	89.4	144	11,500
FF1	2.5	86.5	317	25,360
Means:	3.0	87.5	178.3	14,260

Table 4. Results of tests for differences in proportion correct between regular training trials and trials in which the stimuli appeared in the four EXFAR positions.

BIRDS TRAINED WITH STIMULI IN FIXED LOCATION:

Subject	Location		Difference in Proportion	
	Training	EXFAR		
C-FF1	.868	.72	.148	z = 2.200 *
C-FF2	.863	.58	.283	z = 4.926 **
FF1	.775	.67	.105	z = 1.603
FF2	.92	.70	.22	z = 4.796 **
FF3	.885	.646	.239	z = 4.512 **
MEANS:	.8621	.6632	.1989	

* $p < .05$
** $p < .01$

BIRDS TRAINED WITH STIMULI IN VARIABLE LOCATIONS:

Subject	Location		Difference in Proportion	
	Training	EXFAR		
FV1	.929	.8237	.1053	z = .8237
FV2	.9461	.917	.0291	z = .8228
FV3	.922	.792	.130	z = 2.952 *
C-FV1	.953	.958	.005	z = .1557
MEANS:	.9375	.8727	.0648	

* $p < .05$

Birds in both the FF and FV groups made more errors on test trials, that is, when the discriminative stimuli appeared in the EXFAR position. For the FF birds the mean proportion correct on the training trials was .8621. Their proportion correct when the stimuli appeared in the EXFAR position during test trials was .6631, a nearly 20% decrease in accuracy. The birds for whom stimuli in the EXFAR position appeared during training also showed a decrease in accuracy from .9375 on training trials to .8727 on the test trials with stimuli in the EXFAR positions, a 6.5% decrease in accuracy.

The training and test data for each bird was also compared by obtaining z-values for the difference in proportion correct for their training and test trials (see Table 4). As expected, given the group comparisons, z-values for the difference between the proportion of correct responses on training and test trials were significant for four of the five birds trained with the stimuli only in the center position, and was significant for only one of the four birds trained with the stimuli in the variable positions.

A two-way mixed analysis of variance (see Table 5) revealed that the overall proportion correct for the birds trained in the FF condition was significantly lower than that for those trained in the FV condition ($F(1,7) = 24.447$, $p < .002$). The overall decrease in accuracy on the EXFAR positions as compared to performance on the training positions was also highly significant ($F(1,7) = 33.240$, $p < .001$). Because the interaction between these two main effects (FF vs FV Condition as well as Training vs Test trial performance) was differences in proportion correct for the birds trained in the FF and FV significant

Table 5. Two-way mixed ANOVA on proportion correct for birds trained under the FF and FV conditions with stimuli in the training and the EXFAR locations.

Source	SS	*df*	MS	F	*p*
Total	.22957	17			
Between Subjects	.11597	8			
Condition (FF/FV)	.09016	1	.09016	24.447	.002*
Error$_b$	.02581	7	.00369		
Within Subjects	.11360	9			
Trials (Training/Test)	.01628	1	.07729	33.240	.001**
Trials x Condition	.02003	1	.02003	8.612	.022*
Error$_w$	.01628	7	.00233		

* $p < .05$

** $p < .01$

(*F*(1,7)= 8.612, p = .022) separate *t*-tests were done to compare the conditions. As was expected, assuming a given location effect, the difference in accuracy on discrimination of the stimuli in the training location as opposed to the EXFAR locations for the birds trained under the FF Condition was highly significant, *t*(4) = 6.193, *p* < .01; while the difference for the birds trained under the FV Condition was not significant, *t*(3) = 2.048, *p* > .05.

These results support the prediction that birds trained to discriminate between forms appearing in a specific visual location will be less likely to recognize these forms when they appear in other locations, compared with birds trained to discriminate forms appearing in multiple locations from the start.

Birds trained to discriminate stimuli appearing in variable locations learned more quickly overall than birds trained to discriminate the stimuli in one fixed central location. It is possible that learning to "search" the screen for the stimuli forced the birds trained with the stimuli in unpredictable locations to look more directly at the stimuli, rather than to rely on quick glances at the center of the screen where the location of the fixed stimuli could be anticipated. This would be predicted by the model proposed by Chase and Heinemann (2001) as more direct visual attention to the stimuli would result in the more rapid accumulation of accurate visual memory records of the stimulus patterns, which could then be used for comparison to stimulus presentations on successive trials.

Experiment 3.

Effects of a Novel Form on Discrimination Accuracy

If the decreased accuracy shown by the FF birds when the stimuli were shown in the EXFAR location was due to failure to visually process reliable records of stimuli in these locations, a novel form presented in the EXFAR location should have no effect on performance. However, if the birds were attending to this location, as was expected for the FV birds, this added form may decrease accuracy on the "x" and "◊ " discrimination. For convenience this additional form will be referred to as a "distracter."

The form used to test for distracter effects was the outline of an achromatic 8-mm by 4-mm rectangle. This form was presented in the EXFAR position on probe trials in which the "x" or "◊ " appeared in the center position of the active area. In order to compare accuracy changes correlated with location of the discriminative stimuli to accuracy changes in the presence of this new form, the location and distracter tests took place on independent trials within test sessions.

Method

Subjects. The subjects were the nine pigeons who acquired the form discrimination.

Apparatus. The apparatus was the same as that used in Experiment 1.

Procedure. Procedures used in training the discrimination are described under Experiment 1. Both the distracter test and the location test data were obtained on independent probe trials during test sessions which were administered on three consecutive days following 90 days of training (including 15 days on reduced reinforcement). Tests for the effects of the presence of the distracter consisted of the presentation of eight "x" probe trials and eight "◊" probe trials during which one or the other of these stimuli appeared in the center position while the rectangle appeared an EXFAR position. Each of the four EXFAR locations displayed the distracter twice in the presence of each of the discriminative stimuli for a total of 16 test trials. These test trials occurred in a random order within the three test sessions of 168 trials (136 training trials plus 32 location and distracter test trials).

Results and Discussion

The proportion correct on distracter trials was compared to that on the training trials (see Table 6). These data are shown separately for birds trained under the FF and for those trained under the FV Conditions. For both groups, accuracy was lower on trials in which the distracter was shown than on training trials within the same session, a decrease in accuracy of 8% for the FF birds and 10% for the FV birds. A two-way mixed ANOVA (Table 7) showed this decrease in accuracy to be significant, $F(1,7) = 17.307$, $p < .01$. However, the difference between the groups was not significant, $F(1,7) = 4.053$, $p > .05$). These data, together with the lack of a significant interaction, $F(1,7) = .191$, $p > .05$, between training conditions and the training/test performance, suggests that both groups were equally affected by the distracter. This finding was reinforced by examination of the z-score differences between the proportion correct on the training and test trials obtained separately for each bird (see Table 6). Two of

Table 6. Results of test for differences in proportion correct between regular training trials and trials in which an uninformative stimulus ("distracter") was presented in the four EXFAR positions.

BIRDS TRAINED WITH STIMULI IN FIXED LOCATION:

Subject	Condition		Difference	Probability
	No Distracter	Distracter		
CF1	.868	.729	.139	$z = 2.570$ *
CF2	.863	.770	.093	$z = 1.704$
FF1	.775	.750	.025	$z = 0.375$
FF2	.92	.830	.090	$z = 2.112$ *
FF3	.885	.833	.052	$z = 1.047$
MEANS:	.8621	.7824	.0797	

*$p < .05$

BIRDS TRAINED WITH STIMULI IN VARIABLE LOCATIONS:

Subject	Condition		Difference	Probability
	No Distracter	Distracter		
FV1	.929	.708	.105	$z = 4.957$ **
FV2	.946	.917	.029	$z = .8228$
FV3	.922	.833	.089	$z = 2.570$ *
CV1	.953	.896	.057	$z = 1.667$
MEANS:	.9375	.8385		

*$p < .05$
**$p < .01$

Table 7. Two-way mixed ANOVA on proportion correct for birds trained under the FF and FV conditions with the "distracter" in the EXFAR location.

Source	SS	*df*	MS	F	*p*
Total		1			
Between Subjects	.05217	8			
Condition (FF/FV)	.01913	1	.01913	4.053	.084
Error_b	.03304	7	.00472		
Within Subjects	.05062	9			
Trials (Training/Test) **	.03560	1	.03560	17.307	.004
Trials x Condition	.00041	1	.00041	.191	.674
Error_w	.01461	7	.00208		

** $p < .01$

five birds trained in the FF Condition performed significantly poorer on the distracter trials than they did on training trials, and two of four birds trained in the FV Condition performed significantly poorer on distracter trials than they did on training trials.

These findings do not support the prediction that subjects trained with stimuli in variable locations are more likely to be affected by the presence of an uninformative stimulus than are those trained to process visual information presented in one specific location only. Thus, the location effect observed in Experiment 2 does not appear to be due to failure to visually process stimuli in non-trained locations.

Experiment 4.

Effects of Distracter Location

The effects of the distracter on the accuracy of the form discrimination when this novel form appeared in the EXFAR location were equivocal. The discriminative performance of two of the birds in the FF Condition and two of the birds in the FV Condition were affected by the distracter. The others did not show a significant decrease in accuracy. The purpose of the present experiment was to determine if the novel form might act as a distracter if it appeared at differing proximities closer to the discriminative stimuli.

Method

Subjects. The same nine pigeons who participated in Experiments 2 and 3 were subjects.

Apparatus. The apparatus was the same as in the previous experiments.

Procedure. A single training session was given following the generalization tests conducted in Experiments 2 and 3. In Experiment 4, as in Experiment 3, the discriminative stimuli appeared in the central position. The distracter was the same as that used in Experiment 3, an outline of an 8-mm by 4-mm achromatic rectangle. The distracter was presented twice in each of the 16 non-central positions (see Figure 3), once with the "x" in the center and once with the "◊" in the center, for a total of 32 test trials. In all other respects these test sessions were the same as those used in Experiments 2 and 3.

Results and Discussion

During each test session there were two trials with the distracter at each of the four locations of each distance: (left, right, upper, lower) Near, (left, right, upper, lower) Medium, (left, right, upper, lower) Far, and (upper left and right, lower left and right) EXFAR (see Figure 3). Figure 8 shows the mean proportion correct for Birds trained under the FF and FV Conditions on trials in which the distracter appeared at each of the four distances from the discriminative stimuli. The FV birds showed a slight tendency toward increased accuracy as the distance of the distracter from the stimulus increased, while no such tendency was apparent for the FF birds (see Tables 8 and 9). These data suggest that distance is not a factor in the distracting effects of the novel form on the discrimination.

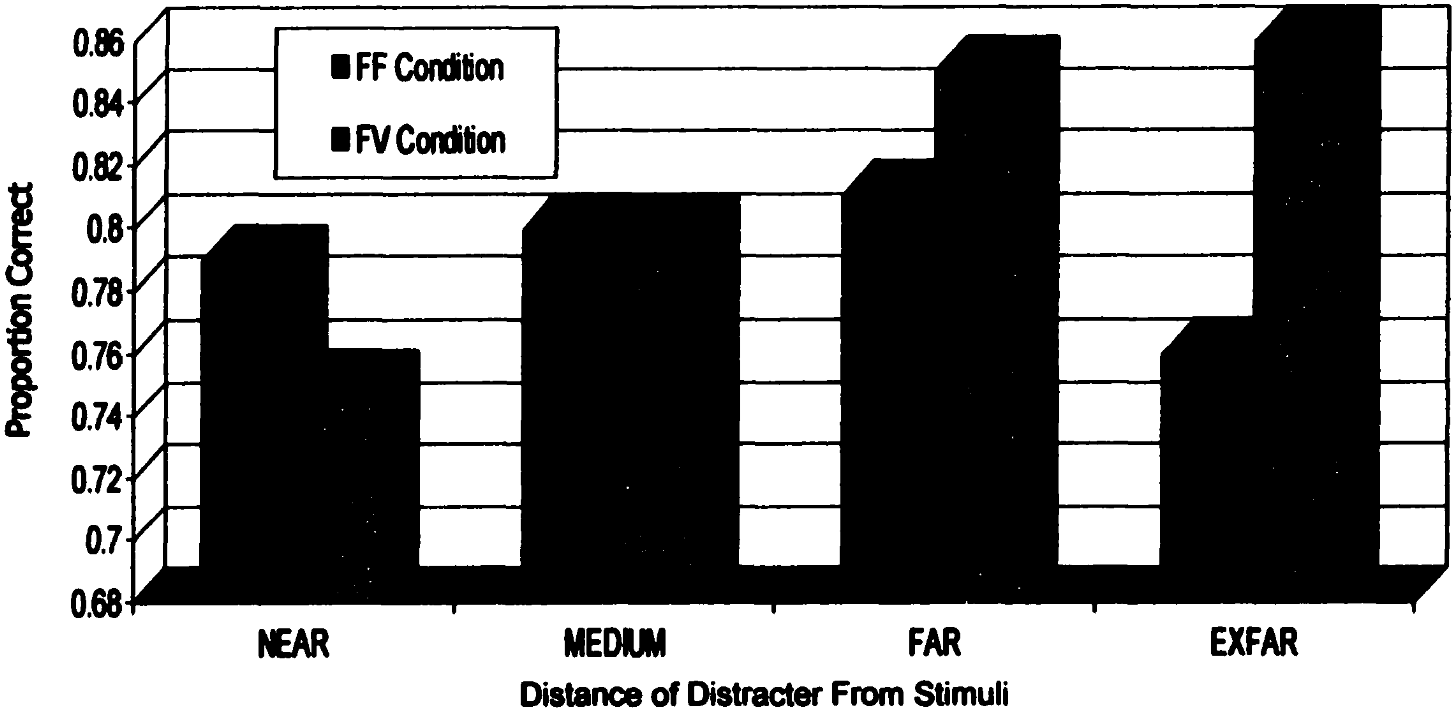

Figure 8. Graph showing distracter effects on the accuracy of birds trained under the Form Fixed and Form Variable Conditions when the distracter appeared at different proximities to the stimuli.

Table 8 . FF and FV birds' proportion of correct responses with the distracter present in locations differing in proximity to the stimuli.

FORM FIXED BIRDS:

		Distracter Distance			
Bird	Training Accuracy	Near	Medium	Far	EXFAR
FF1	.85	.73	.75	.83	.80
FF2	.90	.85	.80	.75	.88
FF3	.84	.90	.75	.80	.73
C-FF1	.92	.75	.88	.90	.75
C-FF2	.85	.73	.83	.78	.73
MEANS:	.87	.79	.80	.81	.76

FORM VARIABLE BIRDS:

		Distracter Distance			
Bird	Training Accuracy	Near	Medium	Far	EXFAR
FV1	.92	.78	.88	.93	.85
FV2	.97	.63	.68	.88	.78
FV3	.89	.80	.80	.83	.95
C-FV1	.98	.78	.85	. 75	.85
MEANS:	.94	.75	.80	.85	.86

Table 9. Two-way mixed ANOVA on proportion correct for birds in FF and FV Conditions with the "distracter" in Near, Medium, Far and EXFAR locations.

Source	SS	*df*	MS	F	*p*
Total	.087344	35			
Between Subjects	.043672				
Condition (FF/FV)	.000302	1	.003022	.488	.507
Error_b	.04337	7	.006195		
Within Subjects	.03212	27			
Distance	.01710	3	.00570	1.176	.343
Trials x Condition	.00041	3	.00658	1.357	.283
Error_w	.01461	21	.004847		

General Discussion

The choice procedure used in the present experiments ensured that all the discriminative stimuli (the red and green rectangles, and the "x" and "◊" forms) were equally correlated with reinforcement (the number of reinforcements were equal since trials did not end until the correct response was made). Thus, none of the discriminative stimuli were exclusively S+ or S-. According to Chase and Heinemann's (2001) model of learning and memory, during acquisition training information correlated with reinforcement is accumulated. This information is used in determining which events within the experimental situation are relevant to the task. This occurs before there is evidence of a discrimination, during the PSP. Following the PSP the accumulated information is used in decision-making.

The effects of the pretraining conditions examined in Experiment 1 demonstrated that extradimensional visual discrimination training can facilitate acquisition of a subsequent discrimination, specifically by shortening the length of the PSP for second task. This experiment also supported Heinemann's suggestion of an inverse relation between stimulus discriminability and PSP length. The supposed "easier" color discrimination was preceded by shorter PSPs and resulted in generally higher *d'* value at asymptote than was the more "difficult" form discrimination. Also, color pretraining appeared to facilitate the acquisition of the form discrimination, and form pretraining facilitated the acquisition of the color discrimination. These results support the concept of a sensory channel being opened during the PSP for the location of stimuli to be discriminated. The facilitative effects of discrimination pretraining—either on intradimesional tasks, such as those reported by Ploog and Williams (1995) or on some extradimensional tasks (Terrace, 1963; Seraganian, 1979; and Frieman & Goyette, 1973)—may be viewed as attributable to the opening of such a sensory channel during the PSP.

Experiments 2, 3 and 4 of the present study differ from most previous studies in which location and distracter effects were examined. One difference was that there was no requirement for the birds to peck directly on the stimuli. Pecks anywhere within the 12.5-cm by 12.5-cm active area of the touch screen were sufficient to initiate the choice and reinforcement contingencies.

As expected, the birds that were trained to discriminate the two form stimuli in a single central location performed less accurately when these stimuli appeared near the four corners of the active area, a distance of 6.4 cm from the training location. However, the effects of changing the location of the discriminative stimuli following Form Fixed training were much smaller than those found in generalization tests conducted by Yamashita (1991). The birds in the present experiments performed at above-chance levels (66% correct) at locations further from the training location than those at which Yamashita's birds initially performed at chance. Of course, unlike the birds in the present experiments, Yamashita's birds were required to peck on a fixation point in order to view the discriminative stimuli. Thus, in Yamashita's experiments the images of the stimuli were likely to stimulate the same retinal locations, while in the present experiments, the retinal areas stimulated probably varied considerably.

In other studies investigating location effects in discrimination or recognition of visual stimuli, the stimuli to be discriminated or recognized appear in an obviously bounded area of the visual field. It seems possible that this bounded area may contribute to the visual pattern, as the subject may be recognizing or not recognizing the discriminative stimulus based on its spatial relationship to the boundary. Moving the stimuli in relation to an apparent boundary may result in decreases in accuracy as a result of a generalization decrement—the relation between the boundary and the location of the stimuli differ if the boundary is treated as part of the stimulus pattern. Heinemann and Kadison (1976), Chase (pilot experiments), and Kirkpatrick-Steger, Wasserman and Biederman (1998) presented their stimuli on a surface that included a clearly defined area in which the stimuli would appear. Heinemann and Kadison used an illuminated circular key 7.62 cm in diameter. Chase's stimuli appeared within a 6-cm by 6-cm square monitor. In experiments by Kirkpatrick-Steger et al., picture stimuli were presented in a 7-cm by 7-cm square button. In the latter study, birds were trained to discriminate the four stimuli in four different locations on this button before testing for location effects in four slightly different positions to "encourage the pigeons to attend to all portions of the viewing screen" (p. 36). Kirkpatrick-Steger et al. considered the birds in their study to be displaying "positional invariance" by recognizing the discriminated drawings when they were viewed in the untrained locations. However, they note that "a pilot study from our laboratory...revealed that training with the stimuli displayed in only one location resulted in poor transfer when the picture was moved to new portions of the screen" (p.36). These findings demonstrate that training to attend to different areas of the screen is instrumental in the subjects' ability to recognize the discriminative stimuli when they appear in other locations, even when these locations are relatively close to the training locations and viewed relative to a circumscribed boundary.

The experiments carried out by Heinemann and Kadison (1976), Chase (pilot experiments), and Kirkpatrick-Steger et al. (1998) all presented the discriminative stimuli only in areas of the display surface corresponding to the central visual field of the pigeon (Yamashita, 1991). Yamashita's birds showed a fairly flat generalization gradient for stimuli presented within 2.2 cm of the central trained location (see Figure 2). Thus, the experimental conditions used in the other above-cited examinations may have been too limiting to allow subjects to demonstrate when, where and to what extent location is or is not processed as a part of stimulus pattern discrimination. Their results would not be likely to generalize to the conditions of the present experiments in which no clearly visible delineating boundary was supplied to which the location of the stimuli could be related. In the present experiment the stimuli were displayed in the center region of a uniform dark surface—the transparent touch screen covering the dark computer monitor in a dark wall of the dimly illuminated black chamber. The birds had few obvious cues, apart from proprioceptive cues from head and body position, providing information about the location in which the stimuli appeared relative to the boundaries of the screen itself. The attempt was to approximate absolute visual location conditions and their effects on discriminative behavior, rather than effects of relative location. The less restrictive nature of the present experimental situation permitted less control over the spatial range of the pigeons' pecking responses, but it afforded a method of observing the birds' generalization capabilities to stimulus location changes over a larger two-dimensional range than any reported previously.

The accuracy of the discrimination in the presence of a distracter form was a measure employed in attempt to determine whether or not the birds attended to locations other than those containing the discriminative stimuli during training. In order to determine whether or not the decreased accuracy of the Fixed Condition birds was due to failure to process information in the new locations, the distracter form was introduced, and a distracter effect was found to occur. Four of the nine birds performed significantly poorer on trials in which the distracter appeared, thus it is likely that the presence of the novel form on the display screen disrupted the acquired discrimination. However, there were no systematic differences in accuracy between the group of birds trained under the Fixed Condition compared to the group trained under the Variable Condition. Furthermore, the effect was independent of the distance between the distracter and the discriminative stimuli. The fact that a distracter effect was indeed found was not a surprise. The surprise was that the birds trained to "attend" to the discriminative stimuli only in one central location for well over 12,000 continuously reinforced training trials were not immune to this distracting effect.

The expectation that a novel form placed at various locations relative to the discriminative stimuli would distract from the discrimination was based on evidence from an experiment by Donis, Heinemann and Chase (1994; Experiment 3) in which pigeons were trained to discriminate two simple forms either presented alone or in the context of two "flanking" stimuli at different separations on each side of the stimuli to be discriminated. The birds trained to discriminate the stimuli with the flanking stimuli at large distances performed as well as those trained with the stimuli alone. Acquisition of the simple-form discrimination was disrupted when the flanking stimuli were presented in close proximity to the discriminative stimuli (0.2 cm of separation), but was not affected when these flanking stimuli occurred at more distant locations (5.5 cm of separation). This "distracter effect" obtained with the flanking stimuli close to the discriminative stimuli presumably was due to simultaneous processing of both the pattern and the flanking stimuli. At more distant locations the flanking stimuli were not processed, and thus did not interfere with the target discrimination.

The unexpected nature of the distracter effect found in Experiments 3 and 4 may be attributable to the behavioral variability of birds trained in both the Fixed and Variable Conditions. It appears likely that some characteristic of the touch screen surface was responsible for the many ineffective beak movements being required in order for the birds to effectively activate both the stimulus region and the choice key regions, encouraging the interesting response behaviors to the appearance of the stimuli on the screen. At the beginning of shaping, the birds directed ballistic pecks toward the illuminated disks behind the touch screen, but these were rapidly replaced with swipe-like pecks by all the birds before the onset of stimulus training. The sweeping movements of the beak across the screen allowed processing of information over more of the display area than would be likely to occur if a single peck to the stimulus was necessary or sufficient to activate the appearance of the choice keys. Thus, birds in both conditions probably examined a fairly large region of the screen.

Although rate of responding was not the measure of interest, it was observed that behavioral persistence was required of the subjects. In all instances, the birds appeared to learn to direct their responses to a larger area of the active stimulus region than was expected—through the use of multiple beak strokes and swipes near and around the stimulus, above the stimulus, and ultimately, as the discrimination was learned, between the stimulus and the associated correct response key.

Particularly informative was bird C-FV2, who acquired the color discrimination quickly and accurately, pecking at or near the stimuli, then displayed increasing inaccuracy correlated with consistent pecking directed at the uppermost portion of the screen, regardless of where the stimuli appeared. This behavior reliably produced the appearance of the choice keys, possibly with less effort, but resulted in only chance response accuracy. Food pellets acquired during correction trials presumably resulted in this bird's behavior being adequately reinforced. Ultimately, when transferred to the form task, this bird failed to acquire the discrimination for the 12,240 trials comprising the training period. Even when switched back to the color discrimination that had previously been learned, thbird's performance never approached the initial accuracy level. This finding is representative of the range of strategies birds may use to respond to various aspects of the experimental situation. Further work with subjects like this one may be useful for enabling the careful structuring of the experimental environment so that results are not exclusive to instrumentation, and the full range of operant behaviors may be observed for these visually intelligent subjects.

Footnotes

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[1] Two mechanical rotary dispensers on top of each experimental chamber were activated by the computer to deliver one food pellet into a cup when the correct response was made. Apparatus problems occurred on occasion—the feeders occasionally failed to deliver a pellet, or delivered more than one pellet. The experimenter was generally able to manually operate the feeders when necessary.

[2] This method of estimating the end of the PSP was based on inspection of the data of the bird who failed to acquire the form discrimination. This bird occasionally had blocks of .75 or greater correct but never two such blocks within a session. Accuracy of .75 has a probability of less than .10 in a block of 17 trials.

[3] The birds were required simply to peck within the active region. This bird at first pecked the colored rectangle in whichever position it appeared. However, this behavior changed and the bird began pecking at the very top of the screen. Because the correct key was illuminated following an error (as a correction procedure was used), food could be obtained reliably at a performance probability of .5 regardless of response accuracy.

APPENDIX A

Shaping and Preliminary Training Procedures

Shaping consisted of the experimenter delivering food into each food cup allowing the birds to eat from them, signaled by the sound of the feeder motor and the pellets dropping into the cup. Next, reinforcement was delivered when the outer key was illuminated and pecked by the bird prior to delivery of food. When these responses were acquired, birds were required to peck the active area of the touch screen in order for the choice key to light up and be pecked for reinforcement.

An autoshaping program was not used. Instead, the experimenter reinforced successive approximations of the desired behavior. It was hoped that there would not be too much individual variation in responding as results would later be more difficult to interpret. As it turned out, there were individual differences during shaping, and these are described here along with a discussion of how these early differences related to later discrimination performance for each bird.

Key Light Training in Box 2

Four birds, C-FF2, C-FV2, FF2, FV2, were shaped to the outer key light and outer feeder in Box 2. They all learned to peck the key light and receive reinforcement from the outer cup on the very first day. Initially, pecks toward the key light were reinforced by the experimenter. First, one peck was reinforced, then two, three, four, five, etc. For some birds as many as 30-40 pecks were required before they were strong and/or accurate enough to be sensed by the touch screen and food was delivered automatically.

Two days later the birds were given the second shaping session which included the ITI. C-FF2 and FF2 both pecked the light at first, then C-FF2 stopped responding, and FF2 started flapping and attacking the screen, so neither completed the program. C-FV2 and FV2 both completed this program without hesitation.

On the third day, all four of these birds completed the outer feeder / ITI program without problems.

Two days later, on the 4th shaping session, birds C-FV2, FF2 and FV2 performed well, while bird C-FF2 stopped, and required additional help from the experimenter using the shaping wire to deliver food. After a few assisted trials, performance improved.

By the next (5th) session the following day, all four birds were performing well on their own on this one-light/one feeder ITI program.

Two days later birds C-FF2 and C-FV2 were presented with a new program consisting of alternating right and left key lights. Neither was able to complete this procedure.

Two days later, all four birds were presented with this new program. A broken house light bulb prevented C-FF2 and C-FV2 from completing the program. After replacing the bulb, birds FF2 and FV2 were run on this program for the first time and both performed extremely well.

The following day, all four birds were run on this 2-light/2-feeder ITI program and performed very well.

Bird C-FF2 was run once again (a 4th time) the next day because it was having trouble retrieving pellets from the inner cup the day before. This apparatus problem was remedied, and C-FF2 completed this program.

After a day off, all four Box 2 birds were given a new program which consisted of 50 right-light/cup trials alternating with 50 left-light/cup trials. All four birds learned this program readily; C-FF2 completed 50 trials in16 minutes, C-FV2 in 35 minutes, FF2 in 25 minutes, FV2 in 20 minutes.

By this time, it was possible to see differences in response behavior. C-FF2 was fast and accurate with pecks to the light. C-FV2 was inaccurate but emitted lots of pecks. FF2 was also not accurate in pecking but active and attentive. FV2 was calm, very focused, a persistent pecker (pecks were like little "bites" to the light).

Key Light Training in Box 1

The other five birds, C-FF1, C-FV1, FF3, FF1, FV1, began shaping to the outer key light and outer feeder in Box 1. During the first session, C-FF1, FF3, FF1 and FV1 all learned to orient toward the screen, but only FV1 made pecks to the light. Bird C-FV1 began training four days later as it was having problems adjusting to the feed pellets. On his first shaping session it learned to orient toward the screen and make some pecks to the light.

The following day on their second shaping session, birds C-FV1 and FV1 both successfully completed the outer key program on their own. Birds C-FF1, FF3 and FF1 still only oriented correctly, but did not peck the light.

The next day, during the third shaping session, FF1 began to make some good pecks to the light. C-FF1 did well, pecking the light and requiring only occasional intervention with the shaping wire. FF3 made no pecks at all to the screen. The other birds (C-FV1 and FV1) continued to perform well.

During the fourth shaping session on the following day, birds FF3 and FF1 both began tentatively to peck toward the light, but stopped responding before the session was completed. All the other birds completed the program without problems.

On the fifth day and session of shaping, the single key program incorporating the 3-sec ITI was instituted. Both FF3 and FF1 began pecking at the light more frequently, but not accurately enough to set off the feeding apparatus. All other birds continued to perform well.

During the following days, the 5th, 6th, 7th, 8th and 9th consecutive sessions, the birds who had learned the procedure continued to do well. Birds C-FF1, C-FV1 and FV1 were able to take occasional days off while the experimenter concentrated on the difficult-to-train birds, FF1 and FF3. These last two birds were restricted in their feeding so that they were brought below 85% of their free-feeding weights (they had been above this weight), and bird FF1 began to show some progress in pecking at the light, though pecks were still inaccurate and it often ceased responding. Bird FF3 made little progress and was retired temporarily after this session.

Bird FF1 showed improvement during its 10th consecutive session, and by the next day, on the 11th session, no longer needed any assistance from the shaping wire. FF1 performed inaccurately but persistently for 60 trials in about

25 minutes.

During the next two days, on the 12th and 13th shaping sessions, FF1 performed 40 independent trials in 12 minutes, and 50 independent trials in 28 minutes. Pecking was still inaccurate, but more persistent.

The following day, birds C-FF1, C-FV1, FF1 and FV1 were presented (along with the Box 2 birds) with the program that had 50 left-response trials alternating with 50 right-response trials. Bird FF1 was slow at first but completed the session well. Birds C-FV1 and FV1 learned this program quickly and without problems. Bird C-FF1 took about twice as long as the others to finish.

By the second session the following day, all four of these birds were able to complete the new program expediently. At this point, the Box 1 and Box 2 birds were on the same schedule.

During this time, the birds' weights fluctuated around 85% of their free-feeding weights due to restricted feeding. Some birds lost weight rapidly and had to be supplemented substantially in their cages, while others, particularly FV1, seemed to maintain weight and gain very quickly if supplemented with even a few pellets. It was determined that many of the birds had been overweight before running weights were calculated, and these birds were gradually brought down to around 80% of their original weights. This appeared to increase motivation in some, but others seemed too thin and at this weight and were subsequently supplemented.

Later Preliminary Training

Following several sessions of alternating 50 right/50 left key light trials, all birds were presented with a program which was intended to teach them to peck the active area of the touch screen (where stimuli would later appear during discrimination training) in order for the key lights to be displayed.

The first of these programs consisted of an initial display of a solid illuminated circle the same size as the key lights, only occurring in the lower central region of the active area. After a peck occurred to this stimulus, a key light was presented and pecked, and the next trial would begin. One of these central circles was presented, followed by trials which began with the presentation of a large illuminated square nearly the size of the active area that required pecks in order to disappear and illuminate the key light. This occurred for three trials until a smaller, narrow rectangular shape appeared in the center of the active area, requiring pecks.

This succession of trials was completed successfully by six of the birds — C-FF2, C-FV2, FF2, FV2, C-FF1 and FF1. Birds FV1 and C-FV1did not respond to these centrally-positioned stimuli and did not learn this program. Therefore, for these birds, the next session's trials did not include the square and rectangular forms, as even the successful birds had experienced some trouble with these, tending to peck at the edges and corners, and thus taking some time to trigger the touch screen in the active area. Instead, a program was instituted that required a peck to a disk of the same proportions as the key lights, which was displayed gradually higher on the screen as trials progressed so that much of the central region of the active area was eventually pecked by the subjects in order to cause the key lights to appear.

Birds responded differently to systematic changes introduced in the program. They also responded differently to nonsystematic changes, such as occasional malfunction of the feeders and noise levels outside the chambers (there was construction taking place in the next room and this was often very loud in the running room). In general, the easily trained birds showed little or no interruption in responding during these circumstances, while the difficult-to-train birds (primarily FF1 and FF3) were often distracted enough to stop responding in the middle of sessions. In general, the behavior of individual birds during shaping and preliminary training was somewhat, though not completely, predictive of their discrimination acquisition, with the quick, accurate birds tending to show higher accuracy levels than the more distractible birds (see Figures 5, 6, 7 and 8 in the text).

Bird FV3 began shaping with the Box 1 birds, but only learned to orient very closely to the key light. After five sessions, it was retired, as there were then four successful birds in Box 2 and three successful birds (with one on the way to becoming successful) in Box 1. As noted above, FF1 was retired after failing to shape to the key light after nine sessions.

These two "retired" birds, (FF3 and FV3) later were successfully shaped and trained to participate in these two conditions. Bird FF1 remained distractible and inaccurate, while bird FV3 became one of the most reliable, though somewhat less accurate, of the subjects.

Ultimately, the four color-trained birds tended to peck at or on the colored stimuli, except for C-FV2, who always pecked very high on the screen. The two more distractible Form Fixed birds (FF1 and FF2) also tended to peck high and to the side of the screen (toward the food cup) both during stimulus presentations and during the brightening of the screen following ITIs. Whether or not this can be viewed as expectation or anticipation, it is clear that the birds respond differently after an error than after a correct response in that they tend to be more attentive to the stimulus change after correct trials—even non-reinforced correct trials.

Behavior During Distracter Testing

All the birds "reacted" to the appearance of the distracter. For FV1, FV2 and FV3 this consisted of increased latency in responding, and wing-flapping. For FF1 and FF3 there was also response latency, as well as cooing and grooming. With FF2 there was a tendency to peck closer to the stimuli than on regular training trials. The other birds generally took longer to respond on trials in which the distracter was presented. All the birds showed decrements in proportion of correct responses overall on the first day of testing.

APPENDIX B

Sequence of Training Events.

(A) Hopper training:

Birds were first trained to eat out of each food hopper when pellets were delivered. During hopper training the screen was unilluminated.

(B) Choice key (key light) training:

Next, the choice keys were illuminated one at a time on the unilluminated screen. When the bird pecked the key light, food was delivered to the hopper nearest this key.

(C) Chaining of key pecking:

One of the discriminative stimuli appeared either in the center location or one of 16 other (variable) locations on the screen. A peck within the active region illuminated the choice key designated as correct for this stimulus. Food was delivered following a peck at this choice key.

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