

Pigeon Perception and Discrimination of Rapidly Changing Texture Stimuli

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The perception and discrimination of rapidly changing texture stimuli by pigeons was examined in a target localization task. Five experienced pigeons were rewarded for finding and pecking at a randomly placed odd target block of small repeated elements embedded in a larger rectangular array of contrasting distractor elements. On dynamic color test trials, the color of the target, distractor, or both of these regions changed at rates of 100, 250, 500, or 1000 ms per frame. The number of colors appearing within such trials also varied. Pigeons performed well above chance in all test conditions, with target-associated changes producing the best discrimination. The results suggest: (a) global relational information can exclusively guide target localization behavior, (b) pigeons can perceptually group and segregate colored textured differences quite rapidly (≤ 100 ms), and (c) pigeons may possess automatic search control processes that can be captured by stimulus-driven changes in the display.

The research described in this article is part of our ongoing efforts to understand the mechanisms of visual perception and cognition in pigeons, and their comparative relations to mammalian visual perception and cognition. Our overall goal is to discern the perceptual (Cook, 1992a) and decisional processes (Cook & Wixted, 1997) involved from the point when external visual information first impinges on the animal to its final behavioral reaction to this information. By looking in detail at each aspect of how pigeons accomplish complex visual discriminations, we hope to uncover the cognitive and neural mechanisms used by these visually sophisticated animals and to compare them with those mechanisms found in other types of animals, including humans.

One way we have investigated these questions is by examining in detail how pigeons process and discriminate visual textures (Cook, 1992a, 1992b, 1992c, 1993a, 1993b; Cook, Cavoto, & Cavoto, 1995, 1996; Cook, Katz, & Cavoto, 1997; Cook & Wixted, 1997). Texture stimuli are multidimensional, multielement visual patterns in which global target and distractor regions are arranged from the grouping of smaller component elements (see examples in Figure 1, Beck, 1966, 1982; Julesz, 1981; Marr, 1982). Our results to date suggest that the early visual mechanisms used

to process multidimensional textured information are highly analogous in pigeons and humans despite the differences in the size and fundamental organization of their visual pathways (Pearson, 1972; Zeigler & Bischof, 1993; Zeki, 1993). It has been found that pigeons, like humans, probably discriminate visual textures by means of early parallel mechanisms capable of perceptually grouping and segregating featural differences over large areas (Cook, 1992a, 1992b, 1993a; Cook et al., 1996). These mechanisms presumably function to rapidly extract information about object boundaries and surfaces from visual scenes for the pigeons (Cook, 1992b, 1993b; Cook et al., in press).

This article reports new results that broaden and deepen the understanding of texture stimulus perception and discrimination by pigeons. The experiment specifically focused on their capabilities to rapidly integrate visual information across successive experiences. This was done by comparing search performance with dynamically changing and static texture displays in a target localization task (Cook, 1992a). In this procedure, the pigeons' task on each trial is to find and peck a small odd target region randomly placed within a larger, contrasting distractor surround. As illustrated in Figure 1, target-distractor differences can be made from elements of different colors (e.g., a 7×7 target block of green squares randomly located in a 26×18 array of red squares) or of different shapes (e.g., a target block of blue dots randomly located in an array of blue open circles). In the current experiment, as in our previous research, the location and specific color or shape values forming these global target and distractor regions on each trial were randomized on every trial of a session. Of more importance to the present experiment is to note that although the identity of the target region was highly variable across baseline trials, the displays themselves were always static within a trial. That is, the nature of the color or shape difference did not change over the duration of a trial. For the 5 highly experienced pigeons tested below, this static mode of display presentation characterized their entire prior experience and

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Additional material and examples of the display types found in this article can be found at Robert G. Cook's World Wide Web address: <http://www.tufts.edu/~rcook1>.

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still formed the majority of trials in the current experiment. It is against this backdrop that we introduced the key experimental manipulation, testing the pigeons with texture displays that rapidly and dynamically changed their relevant properties within the course of a single presentation.

These dynamic trials used a modification of the rapid serial visual presentation (RSVP) procedure frequently used in perceptual research with humans (Intraub, 1980, 1981; Juola, 1988; Kanwisher, 1991; Lawrence, 1971). On these dynamic RSVP test trials, the elements defining the display changed color at regular intervals within a single trial (only color trials were tested in this manner in the present experiment). The rates of color change tested involved successive intervals of 100, 250, 500, or 1,000 ms per frame. Examples of these different rates of change over the initial 1,000 ms of a trial are shown in Figure 2. In addition to these variations in the rate of change over successive frames, the type of change in the display was also manipulated. In the *target-variable* conditions, the color of the target elements changed across successive frames within a trial while the color of the distractor elements was held constant. In the *distractor-variable* conditions, the color of the distractor elements changed across frames, while the color of the target elements remained the same. In the *display-variable* conditions, both the color of the target and the distractor elements were simultaneously changed across successive frames of each trial. During all these moment-to-moment transformations of the stimulus display, the pigeons' task remained the same as on the static baseline trials—find and peck the target's location. This focus on the visual integration and search for information across successive displays within a trial is different from many previous approaches to examining sequentially presented stimuli in pigeons, where the primary focus has been more on discriminating the sequence of slowly presented simple stimuli or the ordered production of responses to such stimuli (e.g., MacDonald, 1993; Terrace & McGonigle, 1994; Weisman, Wasserman, Dodd, & Larew, 1980).

We believe that pigeons' reactions to these dynamic texture displays have direct implications for several issues concerning avian visual perception and performance. The first issue centers on the time course and speed of early visual processing by pigeons. One defining property of human texture segregation is its rapidity, with texture differences detected in as little as 100 ms (Bergen & Julesz, 1983; Gurnsey & Browse, 1989). Is texture discrimination and perceptual grouping equally fast in pigeons? If it were, it would provide further evidence that pigeons process these displays in a preattentive parallel-like fashion. In an earlier study (Cook, 1992a), it was suggested that pigeons might be able to detect targets in textured stimuli in perhaps as little as 150 ms. This estimate was derived indirectly, however, by subtracting the time it takes to physically peck the displays (as estimated from the mean interresponse interval of pecks made after finding the target) from the reaction time to locate and first peck the target.

Our intention in this experiment was to provide a more direct answer to this question by looking at the pigeons' performance with the different rates of stimulus change. For

example, if the visual mechanisms for detecting and discriminating a target's location take longer to operate than the duration of an individual frame, then the pigeons should be unable to discriminate such displays and those changing at rates faster than this value (this argument is further developed in the Discussion). Thus, we were particularly interested in when and in what manner the pigeons would begin to fail in their processing of the different types of dynamic displays.

Given that the rapidly shifting character of dynamic RSVP displays also provided very little time to identify the different color values presented within a trial, the present experiment allowed us to examine the relative contribution of relational and absolute features to the discrimination of textured stimuli. How would the pigeons react to a rapid succession of many different target-distractor contrasts whose primary, if not only, source of discriminative information was relational in nature? Previous results with static texture displays (Cook, 1992a; Cook et al., 1995) have suggested that the pigeons learn to respond to these type of stimuli on the basis of an abstract discrimination rule deriving from the invariant oddity relation present in each of the displays—perhaps conceiving of their search task as locating a target figure on a ground—rather than memorizing the absolute identity of each of the individual stimuli in their training set (e.g., Carter & Werner, 1978; Heinemann, 1990; Vaughan & Greene, 1984; Wasserman et al., 1996). If this is true, it would predict that the pigeons should be able to continue and perform their basic task, providing additional converging evidence that these types of simultaneous texture discriminations are perceived and responded to in a highly relational manner by the pigeons (Cook, 1992a, 1993a; Cook et al., 1995; Cook, Katz, & Cavoto, in press). This type of outcome would also be consistent with the hypothesis that the pigeon perceptual system integrates successive views of a visual scene by rapidly coordinating the global, large-scale relational attributes of a scene rather than by matching absolute local details, a result consistent with many observations from the human perceptual literature (Biederman, 1987; Marr, 1982; Navon, 1977; Palmer & Bucher, 1981; Rensink, O'Regan, & Clark, 1997).

The final issue addressed by this experiment concerns the potential role of stimulus-driven selection processes in controlling the visual search behavior of pigeons. It has recently been proposed that human visual selection is a combination of two processes: one consisting of a top-down, goal-driven form of directed attention and a second mechanism consisting of a bottom-up, stimulus-driven, interrupt-like process (e.g., Bravo & Nakayama, 1992; Yantis & Johnson, 1990). The latter interrupt-like *attentional capture* mechanism is proposed to involuntarily direct processing to the portions of a display that contain attributes such as abrupt stimulus onsets, offsets, novel objects, or large changes in luminance (see Yantis, 1993, for a review). Is avian visual cognition similarly organized, relying on a set of automatic processes to allocate processing to novel or changing portions of the visual world? Such an automatic selection mechanism, for instance, would be very helpful in noticing and avoiding sudden attacks by predators or

detecting the slight movements of stationary prey. If such selection mechanisms exist, we hypothesized that the transient changes in color produced by the target-variable displays might serve to help attract a pigeon's processing attention to the location of such targets. If so, then one might see either higher accuracy or faster reaction times to the target areas of such test conditions in comparison to the distractor- or display-variable conditions.

Method

Animals

Five highly experienced male White Carneaux pigeons (*Columba livia*) maintained at 80% of their free-feeding weights were used in the experiment. No preliminary training was needed, as each pigeon had over 4 years of experience with the target localization task (Cook, 1992a, 1992b, 1993a; Cook et al., 1996).

Apparatus

Testing was done in a flat-black Plexiglas chamber (38 cm wide $\times$ 36 cm deep $\times$ 38 cm high). All stimuli were presented on a color computer monitor (NEC MultiSync 2A; Wooddale, IL) visible through a 26 $\times$ 18 cm viewing window in the middle of the front panel of the chamber. The viewing window's bottom edge was 20 cm above the chamber floor. A thin piece of glass mounted in this window protected the monitor. Pecks to the monitor screen were detected by an infrared touch screen (resolution of 80 $\times$ 48; EMS Systems, Champaign, IL) mounted behind a 40-mm wide Plexiglas ledge that went around the inside edge of the viewing window. A 28-V houselight was located in the ceiling and was illuminated at all times, except when an incorrect choice was made. A food hopper was located in the middle of the front panel, its access hole flush to the floor.

All experimental events were controlled and recorded with a 386-class computer. A video card (VGA Wonder; ATI Technologies, Scarborough, Ontario, Canada) controlled the monitor in the SVGA graphics mode (800 $\times$ 600 pixels). Computer-controlled relays (Metrabyte, Taunton, MA) operated the hopper and houselight. All programming was done in QuickBasic (1989) with an attached graphics library (Xgraf, 1989). Direct manipulation of the video card's palette was used to change a display's colors over successive RSVP frames.

Procedure

Texture display composition. All texture displays were 20 $\times$ 13 cm in size and consisted of 468 small colored shape elements arranged in a 26 $\times$ 18 rectangular matrix. The target region on each trial consisted of a 7 $\times$ 7 block of elements randomly located within the larger matrix of surrounding distractor elements. The target region's location was randomly determined on each trial from 240 possible locations. All elements of the static baseline and dynamic RSVP displays were created from combinations of 20 colors and 34 shapes. Depending on their shape, these elements were 3–6 mm in size (some examples can be seen in Cook, 1992a; Cook et al., 1995). The color values were blue SVGA palette #1, green #2, cyan #3, red #4, purple #5, gray #7, brown #20, teal #24, light blue #25, royal purple #33, rose #37, maroon #38, coral #39, forest green #42, pale orange #46, lavender #47, sea green #51, orange #52, yellow #54, and white #63.

The target and distractor elements of the 12,920 possible color displays differed in color but not shape (20 target colors $\times$ 20 distractor colors $\times$ 34 shapes minus uniform displays), whereas those of the 22,440 possible shape displays differed in shape but not color (34 target shapes $\times$ 34 distractor shapes $\times$ 20 colors minus uniform displays). Just prior to the experiment the pigeons were being tested daily in 140-trial sessions consisting of 70 color and 70 shape displays. These baseline displays were randomly picked for each session from the total pool of 35,360 stimuli.

Discrimination testing procedure. On each of the 140 target localization trials of a session, a pigeon's task was to locate the display's target region. Each trial began with a single peck to a 2-cm circular white ready signal. This signal was randomly located in the upper two thirds of the display area on each trial. This darkened the computer screen for 0.1 s, followed by the presentation of either a baseline or RSVP display. In both cases, if a pigeon accumulated five pecks to the target region (the area of the target and the immediately adjacent row and column of distractor elements around it) prior to accumulating five pecks to the distractor region, an accurate localization response was judged to have occurred and the food hopper was raised for 2 s. If the response was judged incorrect (i.e., to the distractor region), the display was turned off and the overhead houselight extinguished for 10 s. After either of these consequences, an illuminated 5-s intertrial interval separated the trials. Chance performance in this task is 30% as empirically determined from uniform probe trials by Cook et al. (1996).

Dynamic test conditions. Nine modified RSVP conditions were tested in the experiment: three target-variable, three distractor-variable, and three display-variable conditions. Each of these nine conditions was tested at each of four rates of display change (100, 250, 500, and 1000 ms per individual frame). In the RSVP conditions, the target remained stationary in one location across successive frames within a trial. Between trials the target's location in the display was randomized in the same way as on static trials. Because of programming constraints on rapidly changing shape information in these textured displays, only color differences were tested in the RSVP conditions. All colors shown in the RSVP trials were selected at random from the pool of 20 total colors on each trial.

In the three target-variable conditions (*blinking target*, *two target*, *six target*), the color of the elements defining the target region were changed as a group across successive presentation frames of a trial. In the *blinking-target* condition, the color of the target elements alternated between two values across frames, first contrasting with the color of the distractor elements and then matching them on every other frame. This alternation caused the target region to blink on and off. In the *two-target* condition, the color of the target region alternated between two values across frames. Both of these values differed from the color of the distractor elements, which remained the same across frames. In the *six-target* condition, the color of the target elements was switched among six different values across successive frames. These six target colors all differed from the color of the constant distractor elements. On each trial, these randomly picked color values were randomly ordered into a sequence that was repeated throughout a trial.

The three distractor-variable conditions (*blinking distractor*, *two distractor*, *six distractor*) were the complement of the target-variable conditions, except that the color of the distractor elements changed across successive frames while the color of the target elements remained constant.

The three display-variable conditions (*target-distractor reversal*, *two display*, *six display*) differed from the previous conditions in that both the target and distractor regions changed colors across

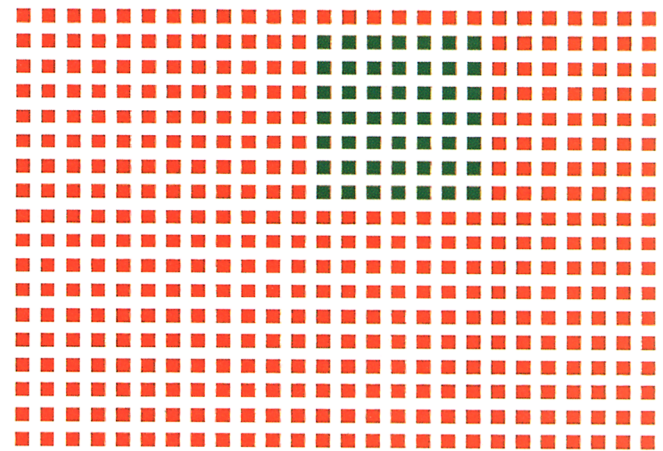
successive frames. In the target–distractor reversal condition, the colors composing the target and distractor elements reversed over alternating frames. In the two-display condition, two completely different displays (4 total colors) alternated across frames. In the six-display condition, six different displays (12 total colors) were randomly streamed across successive frames of a trial (see Figure 2).

The experiment was conducted for 33 sessions. Each session consisted of 92 randomly selected color and shape static baseline displays and 48 color RSVP trials (6 conditions $\times$ 4 rates repeated twice). The first 13 sessions tested only the blinking-target, blinking-distractor, target–distractor reversal, two-target, two-distractor, and two-display conditions. The last 20 sessions tested only the two-target, two-distractor, two-display, six-target, six-distractor, and six-display conditions. Subsequent analyses revealed no differences among the conditions shared between these two blocks of sessions, so the data from all 33 sessions have been combined for the analyses described next.

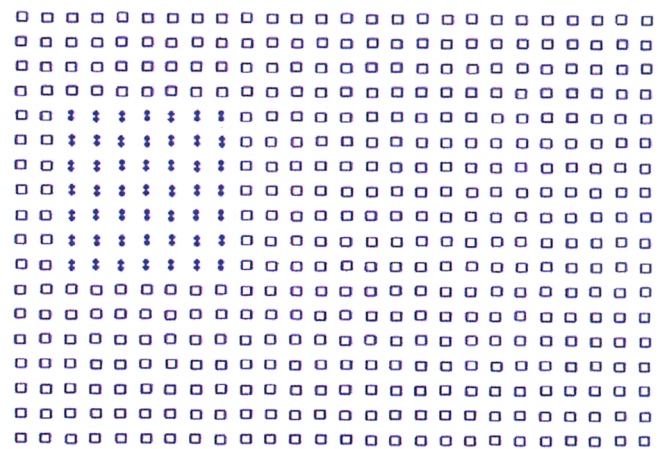
Results

Two fundamental questions keyed our analyses of these data: (a) How much, if any, information did the pigeons extract about the target's location during RSVP presentations? and (b) How did the changes produced by the target-, distractor-, or display-variable conditions affect this performance? The first of these two questions can be answered by looking at RSVP performance as referenced to two values. The first of these values is the probability of being correct by chance, which provides a reference point for when no information concerning the target's location is available to the pigeons. The second value is the probability of accurately locating a target in the static color baseline displays, which provides a reference point for performance within a trial when no changes have been made to a display. The issues raised by the second question can be addressed by comparing performance in the target-, distractor-, and display-variable conditions as influenced by the rate (100, 250, 500, 1000 ms) and numbers of changes (1, 2, 6) occurring within a trial.

For all of our primary analyses, we concentrated on the target localization accuracy of the pigeon's first peck to a display. This response measure was used because it best isolates the effects of display change on the pigeons' search and target localization behavior (Cook, 1992a). The three panels of Figure 3 show mean first-peck target localization accuracy for the target-variable, distractor-variable and display-variable conditions, respectively, as a function of the rate at which the display changed within a trial. The lower reference line in each figure is the chance target localization value (30%; Cook et al., 1996). The upper reference line in each figure shows mean performance with the static color baseline displays. As they also involved the discrimination of color differences, these trials were considered the most appropriate for comparison with performance in the various RSVP conditions. Mean first-peck accuracy on static color baseline trials during the experiment was 76% (for completeness, static shape baseline first-peck accuracy was 66%). The mean first-peck reaction time (RT) on static color baseline trials was 1201 ms. Mean first-peck RT for all dynamic RSVP trials was highly comparable ($M = 1151$



COLOR



SHAPE

Figure 1. Examples of static color and shape texture displays used in the experiment. The location of the odd target region was randomly varied across trials, as were the colors and shapes used to make up each stimulus.

ms) and did not statistically differ from RTs on static baseline color trials, paired t test, $t(4) < 1$ (all statistical tests reported in this article used an alpha level set at $p \leq .05$). The similar duration of the RTs on static and dynamic trials suggest that the pigeons' localization behavior was not disrupted by the novelty of the rapidly changing displays. These RT values suggest that the pigeons experienced on average about 10, 4, 2, and 1 display changes for the 100, 250, 500, and 1000 ms rates, respectively, before completing their initial discriminative response on RSVP trials.

Figure 3 clearly shows that the pigeons successfully extracted at least some target location information during all of the dynamic RSVP conditions. Mean first-peck accuracy at each rate and condition was significantly above chance as tested by both single mean t tests, all $t_s(4) > 3.18$, and binomial tests that used an expected value of 30%. Examin-

ing the pigeons' performance across the three panels, it is clear that accuracy in the target-variable conditions (upper panel of Figure 3) was equal to or better than static color baseline performance and was generally not influenced by changes in frame rate. Distractor- and display-variable conditions (middle and lower panels of Figure 3) showed a different pattern of performance, with both of these supporting accuracy that was generally below static color performance but that increased with slower frame rates.

When compared to static color baseline performance by a series of repeated measures analyses of variance (ANOVAs), critical value of $F(1, 4) \geq 7.7$, first-peck accuracies for the distractor-variable and display-variable conditions were found to be significantly poorer, except at the 1000 ms rate. The reduced accuracy in these two conditions at the faster rates thus indicates that changing the color of a display's distractor region in the first 1000 ms interferes with the normal target localization process. Given the pigeons' mean RTs in these conditions, the lack of any effect at the 1000 ms rate is to be expected, because at this rate the display had not yet changed or had just changed in its color when the pigeons' were first responding to these dynamic displays. As such, they were functionally static trials at this point in their response sequence.

To investigate how the rate of change (100, 250, 500, and 1000 ms) and number of changes (1, 2, and 6) in the RSVP conditions influenced performance, we next compared first-peck accuracy in the different distractor-variable and display-variable conditions by using separate repeated measures ANOVAs (Number of Changes $\times$ Temporal Rate). For the distractor-variable condition there were both significant main effects of number of changes, $F(2, 8) = 12.2$, and temporal rate, $F(3, 12) = 19.2$. The ranking of mean first-peck accuracy across these conditions was as follows: two distractor (68%) > six distractor (66%) > blinking distractor (56%). The ranking of mean first-peck accuracy across the different rates was as follows: 1000 ms (71%) > 500 ms (66%) > 100 ms (59%) > 250 ms (58%). These two factors also significantly interacted with one another, $F(6, 24) = 5.8$. This interaction reflects the substantially greater affect of fast presentation rates in the blinking-distractor condition, especially at the 250 ms rate, relative to the two- and six-distractor conditions. An identical analysis of first-peck RT found no significant main effects or interaction of temporal rate and number of changes among the distractor-variable conditions (overall $M = 1137$ ms).

For the display-variable conditions, the same analysis revealed significant main effects for both number of changes, $F(2, 8) = 12.1$, and temporal rate, $F(3, 12) = 13.1$, but no interaction between these factors. The ranking of mean first-peck accuracy across these conditions was as follows: two display (71%) > six display (69%) > target-distractor reversal (61%). The pattern of mean first-peck accuracy across rate was 1000 ms (74%) > 500 ms (71%) > 250 ms (62%) > 100 ms (61%). An identical analysis of first-peck RT found no significant main effects or interaction of temporal rate and number of changes among the display-variable conditions (overall $M = 1133$ ms).

Overall, the pattern of results for the distractor- and display-variable conditions were highly similar. Both showed

decreasing first-peck accuracy as the rate of presentation and the number of changes increased. Thus, in general as the total amount of change (Number of Changes $\times$ Temporal Rate) in the distractor region experienced over the first 1000 ms increased, the worse the pigeons performed. There were two apparent exceptions to this total change hypothesis, however. The first involved the blinking-distractor condition. Despite the fewer color changes associated with this specific condition in comparison to the others, its periods of display uniformity did cause a disruption in responding beyond that predicted by the simple total change hypothesis. The other exception involved the target-distractor reversal condition, where the alternating reversal of the colors' roles seemed to similarly disrupt performance to a greater degree than expected solely by a total change account.

The general pattern of performance in the target-variable conditions was clearly different from that observed in the display- and distractor-variable conditions. Mean first-peck accuracy for these displays was not strongly influenced by display rate and it was consistently equal to or better than that recorded for the static color displays. Accuracy significantly exceeded the baseline condition in the six-target condition at the 100, 250, and 500 ms rates and in the two-target condition at the 500 ms rate (all critical values of $F(1, 4) \geq 7.7$). Accuracies for the remaining two- and six-target values were not significantly different from the static color displays. Mean first-peck accuracies in the blinking-target condition were found to be significantly below baseline accuracy at the 100, 250, and 500 ms rates. This latter reduction in accuracy, however, was far less than those recorded in the comparable distractor- and display-variable conditions.

The ANOVA comparing the effects of temporal rate and number of changes within the target-variable conditions revealed that first-peck accuracy significantly differed as a function of the number of changes, $F(2, 8) = 24$. The ranking of mean accuracy across these three conditions was as follows: six target (83%) > two target (79%) > blinking target (70%). In contrast to the distractor- and display-variable conditions, there was no significant main effect of temporal rate, $F(3, 12) = 0.2$, or its interaction with number of changes, $F(6, 24) = 1.2$. Mean accuracy across rate for the target-variable conditions was 1000 ms (76%) = 500 ms (78%) = 250 ms (78%) = 100 ms (77%). An identical analysis of first-peck RT found no significant main effects or interaction of temporal rate and number of changes among these target-variable conditions (overall $M = 1208$ ms).

Separate analyses examining criterion target localization accuracy—the measure used to determine whether the pigeons were reinforced on each trial and which is based on all pecks emitted within a trial—essentially mirrored those for first-peck accuracy. Mean criterion target localization accuracy on static color trials was 81%, with the pigeons taking a mean duration of 4104 ms to complete the entire response requirement. The small 5% accuracy increase between the first and final responses to the displays indicates that little additional processing occurred after the first initial contact with the stimulus. This suggests the majority of the target search occurred within the first few hundred milliseconds of a display's onset and was essentially completed by

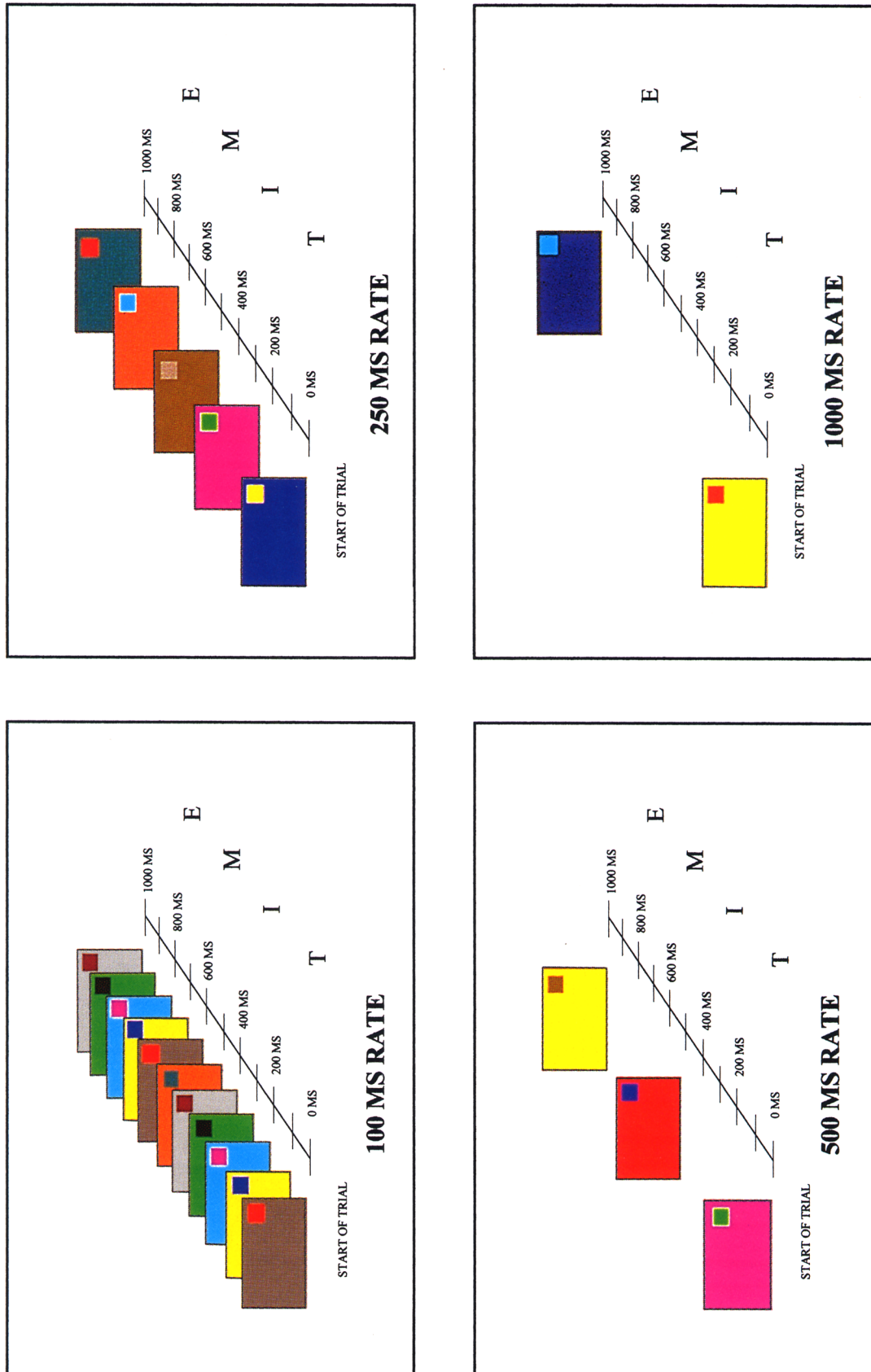


Figure 2. Examples of the sequence of the display changes over the first 1,000 ms for each of the four presentation rates tested in the experiment. These illustrations show only the six display-variable condition, one of nine different dynamic stimulus conditions tested with the pigeons. For the purposes of illustration the target and distractor regions of the displays have been completely filled in by color. The actual displays were composed of smaller repeated elements as shown in Figure 1.

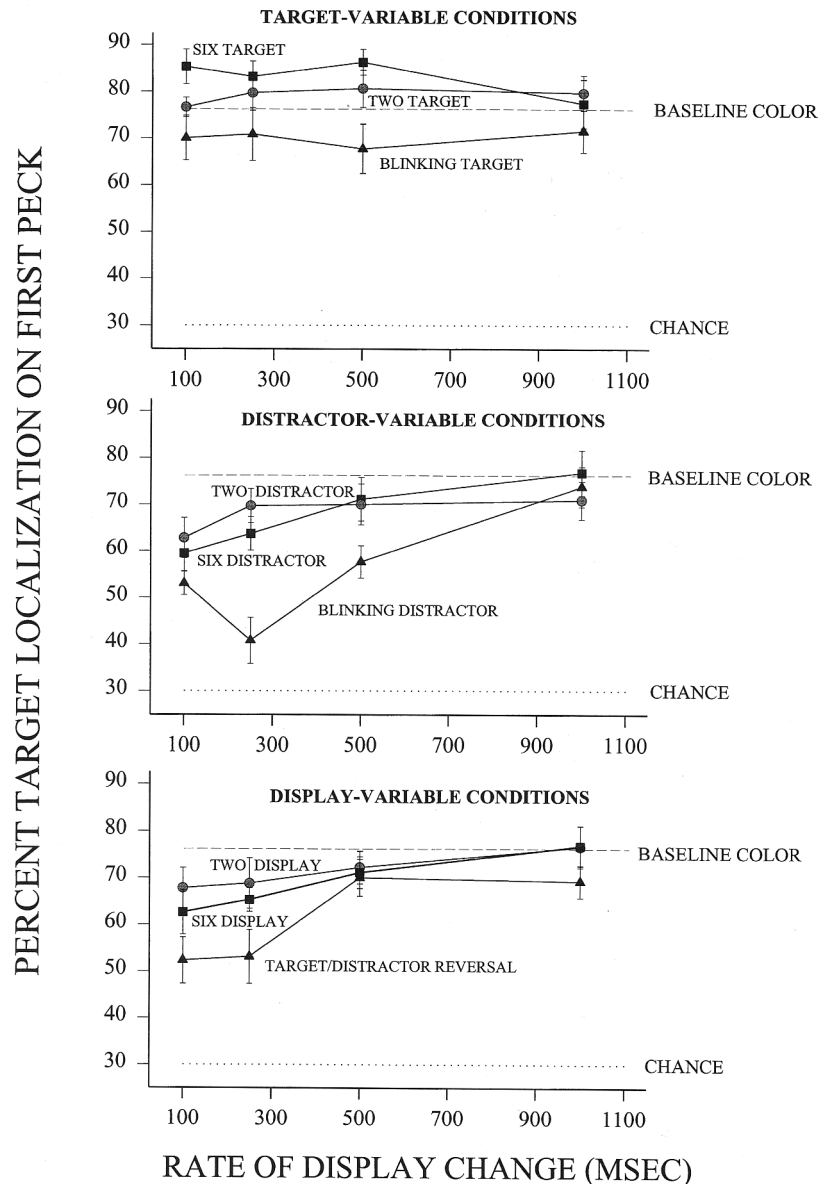


Figure 3. Mean target localization accuracy on the first response for the target-variable, distractor-variable, and display-variable conditions at each of the four display presentation rates. The upper dashed line shows baseline performance with static color displays during the experiment. The bottom dotted line shows chance performance in the task. The error bars show the *SEM* for each condition.

the first response (cf. Cook, 1992a). Mean response time on dynamic RSVP trials was not different ($M = 3975$ ms) from that recorded on static color trials. The duration of these total response times indicate that the pigeons experienced approximately 40, 16, 8, and 4 display changes within a trial for each rate (100, 250, 500, 1000 ms), respectively. The one new effect of these cumulative changes was that the pattern of performance in the 1000 ms conditions now looked like those described for faster rates: with a significant reduction in accuracy in the distractor-variable ($M = 71\%$) and display-variable conditions ($M = 75\%$), and a slight elevation in accuracy in the target-variable conditions ($M = 82\%$; the

latter value was not significantly different, however, from static color performance).

Discussion

These results, to our knowledge, are the first documented evidence of the ability of pigeons to process such rapidly presented quasisquential visual information in a target search task. Despite the dynamically changing color values in the various RSVP conditions, the pigeons retained the capacity to locate the target region in these textured stimuli even at the fastest rates. Of most theoretical importance was

performance in the 100 ms display-variable condition, where an entirely new display appeared every 10th of a second, yet accuracy showed only a moderate drop in comparison to the static displays. A second important new finding was the superior localization accuracy observed whenever a display's dynamic changes were associated exclusively with the target—and in some cases actually resulting in elevated performance above that recorded with the highly familiar static displays. As prefaced in the introduction, these results have several implications for our general understanding of how pigeons perceive, search, select, and process complex, hierarchically arranged visual information.

The Temporal Properties of Texture Processing

The first implication concerns the speed at which pigeons visually perceive and perceptually group a textured display's elements. We had previously estimated, by using the indirect subtraction method described in the introduction, that pigeons could perceive textured differences within about a 150 ms time frame (Cook, 1992a). The present RSVP results experimentally verify this estimate and lower its value closer to the range of human texture perception (Bergen & Julesz, 1983; Gurnsey & Browse, 1989). The best evidence for this claim is the pigeons' clear success at localizing targets in the various 100 ms conditions, most especially in the six-display-variable condition, where they experienced unique colors every 100 ms during the time most critical to their determination of the target's location. As such, those perceptual processes needed to detect and group similar colored regional contrasts must have been sufficiently completed within this interval for any type of discrimination to have occurred. Had the pigeons required a longer interval to perceive these target-distractor contrasts, then the rapid succession of colors would have both continuously masked the previous colors and left insufficient time to process the currently displayed pair, and should have made discrimination impossible. Although performance was reduced in display-variable conditions in comparison to the static color displays, it is also clear that dimensionally based target-distractor contrast information, useful to determining the target's location, was available to these pigeons at the highest rates of display presentation.

One might wonder whether at the highest rates the separate frames simply blurred together, fusing into a set of emergent, but stable, colors that in turn controlled performance. Thus, in contrast to the considerations just discussed, this line of argument suggests the pigeons' success in the current tests was due to a failure to resolve the individual frames of the displays. This does not appear to be what happened, however. First, studies of critical flicker-fusion threshold in pigeons verify this animal's capacity to have temporally resolved the frames of these displays even at the fastest rates (Graf, 1969; Hendricks, 1966; Henton, Ellingson, & Edwards, 1981). More directly from this experiment, the pigeons' above chance performance in the target-distractor reversal condition, where the color of the two regions rapidly alternated back and forth, argues empirically against such an interpretation. If at the highest rates the

different colors in each frame had temporally fused into new ones, then this specific condition should have resulted in a psychologically uniform stimulus. This was not the case. Although performance in this potentially confusing condition was lower than when unique colors formed these regions across frames (i.e., the two- and six-display-variable conditions), even this moderate level of accuracy shows the pigeons' capacity to visually resolve the separate frames of the RSVP displays.

These findings have further implications for the time course of the kind of visual information that is extracted from complex hierarchical displays. Overall, these results are consistent with the previous hypothesis that pigeons learn and process textured-based oddity localization tasks by means of the display's relational global properties rather than its local absolute attributes (Cook, 1992a; 1993a; Cook et al., 1995). Again, performance in the 100 ms six-display condition is of most relevance. Because this condition's swiftly changing nature provided little opportunity to identify the absolute individual values of the colors presented on a trial, it would seem that success in this condition could have only been mediated by the relational target-distractor information. Recall that in this condition particular color values appear only briefly once or twice (a total presentation time of between 100–200 ms per color pair) within the 1000 ms taken to normally execute a localization response. Such presentation times are generally not sufficient in duration for pigeons to make absolute stimulus identifications. For instance, in element-compound matching-to-sample experiments, testing stimuli of comparable size to the individual elements of the current task, presentation durations of 100 ms or less are generally too short to support the absolute identification of a sample's properties (Cook, Riley, & Brown, 1992; Lamb & Riley, 1981). Further, when we tried to identify the specific individual colors of such dynamic displays we found it quite difficult, requiring many seconds of careful scrutiny to confidently name the colors. Given these considerations, the pigeons' success in performing with these ephemerally valued, essentially "moment-unique" displays almost certainly must have been mediated by the global visual relations of the contrasting target embedded within the distractor region, and without specific reference to a display's absolute properties. If the pigeons are rapidly extracting this type of higher order visual relation from textured stimuli, it would follow that when asked to respond to the presence or absence of a target contrast in a choice task, that controlled brief presentations should be sufficient to support accurate choice responding. By using a texture-based same-different conditional choice discrimination, Cook and Wixted (1997) recently presented evidence, in the context of another issue, that 100 ms presentation times could support above chance same-different discrimination. Together, the pattern of data from these converging lines of texture research suggests that certain kinds of relational information, especially as mediated by early grouping processes, involving the detection of a target (and possibly objects in general) and its likely location in visual space, are available to the pigeons prior to knowledge about other absolute properties, such as its color.

This differentiation obviously shares much in common

with the proposed distinctions between the separate processing of "where" and "what" information in human visual search and perception research (Atkinson & Braddick, 1989; Green, 1991, 1992; Sagi & Julesz, 1985; Ungerleider & Mishkin, 1982; Zeki, 1993; see also Kirkpatrick-Steger & Wasserman, 1996). Because the target was stationary across successive frames in the present experiment and target localization was not required by Cook and Wixted's (1997) choice task, it cannot be determined from these specific data whether a single 100 ms textured flash is also sufficient for actually localizing the target's position in a textured stimulus. For instance, in the present setting this kind of spatial information could have, and likely did, accumulate over frames within a trial. Nevertheless, although the exact time needed to localize a textured target's position in this information processing sequence is unknown right now, given the temporal properties of the pigeons' responding here, we speculate that this kind of information is present in the first few hundred milliseconds of a texture's presentation, before knowing anything about what it is.

The Role of Stimulus-Driven Processes in Target Localization

It has been proposed that human visual search and selection is the combination of two different processes: one consisting of a top-down, goal-driven form of directed attention and a second mechanism consisting of a bottom-up, stimulus-driven, automatic, interrupt-like process (e.g., Bravo & Nakayama, 1992; Yantis & Johnson, 1990). For instance, recent human research has suggested that spatially localized changes in the luminance, relative novelty, feature onsets, and feature offsets can all automatically capture visual attention and guide it to the location of their occurrence (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990; Theeuwes, 1995; Watson & Humphreys, 1995; Yantis & Johnson, 1990). As mentioned, one of our motivations for the present experiment was to begin exploring what role similar stimulus-driven mechanisms play in avian visual cognition.

Regarding this general issue, the six- and two-target-variable conditions are of most interest. At the higher rates of display change, the pigeons' were far more accurate in these two conditions than in their corresponding distractor-variable conditions, and often better than with the static baseline displays. This facilitation indicates the presence of more information about the target's location in these types of dynamic displays than in the other conditions. What is the source of this facilitative information? One possibility that can be rejected is that with as many as six different targets appearing within a trial, there is a greater probability of a highly discriminable target appearing (even if very briefly) on these trials than in the static baseline condition. When performance is compared with the two- and six-distractor-variable conditions—where the inherent discriminability of the colors are identical to their target-variable cousins—the pigeons only showed facilitation when these color changes were spatially coincident with the target's location.

We propose this facilitation is better attributed to the hypothesis that the pigeon's processing, or attention, was

automatically activated or attracted to the transient visual changes at the target's position, in a manner analogous to the mechanics of stimulus-driven attentional capture in humans. If this latter hypothesis is true, it suggests one reason why the distractor- and display-variable conditions were generally more difficult for the pigeons. For these conditions, the output of such stimulus-driven processes would have competed with the pigeons' learned rule-driven search for the odd target by consistently diverting processing to the changing values of the distractors in such displays.

By using a different type of search task, Shimp and Friedrich (1993) recently presented evidence that a briefly presented stimulus cue (a 50-ms white flash) also seemed to be automatically processed by pigeons, regardless of its relative validity to the subsequently presented target stimulus. Although their final explanation was more associative in nature, it similarly emphasized the general idea that search performance was a conjunction of event-driven and knowledge-driven processes. Although many details clearly remain to be elucidated, these and other search results with pigeons (e.g., Blough, 1989) suggest a promising new direction for exploring the similarities and differences between human and nonhuman animals in the interaction of top-down and bottom-up processes in the selection and control of behavior by visual information.

Besides the new details about the structure and processes of avian visual cognition revealed by this experiment, especially about the timing and type of information extracted from complex texture displays and the contribution of stimulus-driven events to the control of search behavior, these data add to the growing evidence suggesting the functional similarity of human and avian early visual mechanisms (Cook 1992b; Cook et al., 1996). They suggest both species have early perceptual mechanisms for rapidly computing information about the global organization and location of similarity based visual contrasts. They also raise the possibility that these two species share functionally similar control mechanisms for automatically directing visual attention to locations of potential interest. Collectively, such similarities raise some interesting questions. Do these similarities represent homologous visual processes derived from the common ancestry of birds and mammals more than 250 million years ago? Or, do they represent an example of convergent psychological evolution (Shepard, 1984), where species using dissimilar visual architectures (Zeigler & Bischof, 1993) have evolved similar psychological solutions to the shared problems of rapidly and accurately processing the visual world? If the latter is true, it would suggest that the design of certain psychological mechanisms are closely tied to (constrained by) the structure of the physical world they are designed to process.

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Sternberg Appointed Editor of *Contemporary Psychology* (*APA Review of Books*), 1999–2004

The Publications and Communications Board of the American Psychological Association announces the appointment of Robert J. Sternberg, Yale University, as editor of *Contemporary Psychology (APA Review of Books)* for a 6-year term beginning in 1999.

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