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Dimensional Organization and Texture Discrimination in Pigeons

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Two experiments examined the influence of dimensional organization on pigeons' texture perception, using a simultaneous conditional discrimination procedure. Four pigeons were reinforced for pecking at a small group of *target* colored shape elements randomly located within a larger array of *distractor* elements. The target and distractor regions of *feature* displays differed consistently in color or shape, whereas in *conjunctive* displays these regions were formed by conjunctive mixtures of the 2 dimensions. In Experiment 1, pigeons' target-detection accuracy was higher with feature than with conjunctive displays. In Experiment 2, pigeons responded more accurately and humans responded more quickly with feature displays than with 2 variations of conjunctive displays. These results suggest that the early visual mechanisms mediating the perception of dimensional information are similar for both species.

In the experiments reported in this article, I investigated the visual and cognitive mechanisms underlying texture discrimination in pigeons and the relation of these mechanisms to texture segregation in humans. The rapid discrimination of visual textures by humans appears to be mediated by the parallel grouping of perceptually similar elements and their segregation into contrasting regions (Beck, 1966, 1982; Beck, Prazdny, & Rosenfeld, 1983; Grossberg & Mingolla, 1985; Julesz, 1975, 1981). It has been suggested that these preattentive grouping mechanisms play an important role in fundamental visual tasks such as figure–ground determination and the discrimination of object surfaces, edges, and boundaries. Given the requirements for accurate and rapid visual perception during flight, would birds possess similar visual mechanisms for rapidly achieving the same ends? If so, how might these mechanisms be similar to or different from those of mammals, given the large differences in the size and arrangement of their respective nervous systems?

To begin researching such questions, I recently found (Cook, 1992a) that pigeons quickly learn and transfer discriminations of textured visual stimuli apparently on the basis of their global properties. These pigeons had to locate and peck a randomly located target region, comprised of a small group of identically colored shapes or elements, embedded within a larger array of distractor elements. The pigeons readily learned to discriminate target and distractor regions differing in color, shape, or both of these dimensions. This discrimination readily transferred to various types of novel displays—by the end of the experiments, the pigeons were performing with over 17,000 displays formed by the random pairwise combination of 12 shapes and 11 colors. It was suggested that the birds perceived these texture displays much like humans, with the immediate global perception of contrasting textural regions. This in turn acted as the effective stimulus for mediating the ready acquisition and robust positive transfer observed with the pigeons of those experiments.

Recent experiments with humans have found that the dimensional organization of the target and distractor elements of visual displays strongly influences visual search and texture perception processes (Egeth, Virzi, & Garbart, 1984; Quinlan & Humphreys, 1987; Treisman, 1977, 1986; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). For instance, Treisman & Gelade found that when humans look for a target item defined by a conjunction of color and shape properties (e.g., a green *T* in brown *T*s and green *X*s), search latencies increase linearly with the number of distractor items in a display. On the other hand, humans find target items defined by a unique feature (e.g., a blue *T* in brown *T*s and green *X*s) very quickly, regardless of the number of distractors present in a display (Treisman & Gelade, 1980).

These differences in *feature* and *conjunctive* search suggest that multiple processes are involved in visual search. Treisman has argued that one process involves the immediate, simultaneous, and preattentive processing of the different visual features present in the array (Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1990). This process is responsible for the visual "pop out" and rapid detection of uniquely featured target items. The second process involves the serial application of focal attention over the display. Treisman argued that this latter mechanism is either extensively used or required for the accurate detection of conjunctively defined targets. Similar ideas involving the early parsing and subsequent combination of dimensional visual information can also be found in many other theories of human and machine vision (Barrow & Tenenbaum 1978; Broadbent, 1977; Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Hoffman, 1979; Marr, 1982; Neisser, 1967).

The experiments reported here attempted to answer whether analogous processes are operating in the avian visual system. Two experiments were conducted to investigate the

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responses of pigeons to texture displays with target and distractor regions organized in feature and conjunctive dimensional arrangements.

Experiment 1

The pigeons tested in Experiment 1 had previously learned to locate randomly placed target regions within different types of computer-generated texture stimuli (Cook, 1992a). Using a simultaneous conditional discrimination procedure, these pigeons had learned to peck at the smaller or odd region of the display to receive food (see Figure 1). The elements of this randomly embedded target region differed systematically from those of the distractor region in terms of either color, shape, or both of these dimensions. The properties of these regions were selected at random on each trial from a pool of eight colors and eight shapes and were tested in both target and distractor roles over trials.

This same basic target detection task was used in the present experiments to investigate the pigeons' response to feature and conjunctive texture displays. These new displays differed only in their dimensional organization and were designed in accord with feature–conjunctive conventions shown to have a strong influence on texture segregation in humans (Treisman & Gelade, 1980, Experiment 5). In the feature–shape and feature–color conditions (see Figure 2), the target and distractor regions were formed by grouping four different elements according to their shape (e.g., red *square*–green *square* embedded in red *circle*–green *circle*) or color properties (e.g., *red* circle–*red* square embedded in *green* square–*green* circle). For humans, it has been suggested that the ease of discriminating the regions of these feature displays reflects the fact that our early preattentive grouping processes operate independently on separate visual dimensions. For the purposes of the present article, the shape of the component elements is discussed as if it were a unitary dimension, although it is surely an amalgam of many different visual features, such as size, line orientation, number of terminators, and so forth.

In the conjunctive condition, the target and distractor regions were formed by a conjunctive mixture of the color and shape properties of the elements (e.g., *red square–green circle* embedded *red circle–green square*). Hence, the joint status of both dimensions is required to locate its target region. The difficulty that humans have in rapidly perceiving the regions of these displays presumably reflects the limitation in our early perceptual mechanisms for directly grouping or combining visual information across different dimensions. As a consequence, several successive scans of the display, perhaps involving focal attention, are required to accurately identify and locate the target region of such conjunctively mixed displays (the targets are located in the same place in Figure 2). Would pigeons show a similar difficulty in responding to these displays?

One of two outcomes was expected if these feature–conjunctive operations were producing analogous effects in the pigeons. If pigeons traded processing speed for high accuracy, as human subjects are instructed to do, then first-peck reaction times (RTs) should be slower with conjunctive displays than with the feature conditions. This is the typical result obtained with humans (Quinlan & Humphreys, 1987; Treisman & Gelade, 1980; Wolfe et al., 1989). Alternatively, if the pigeons traded accuracy for speed, by responding quickly to all displays, then target-detection accuracy should be lower with

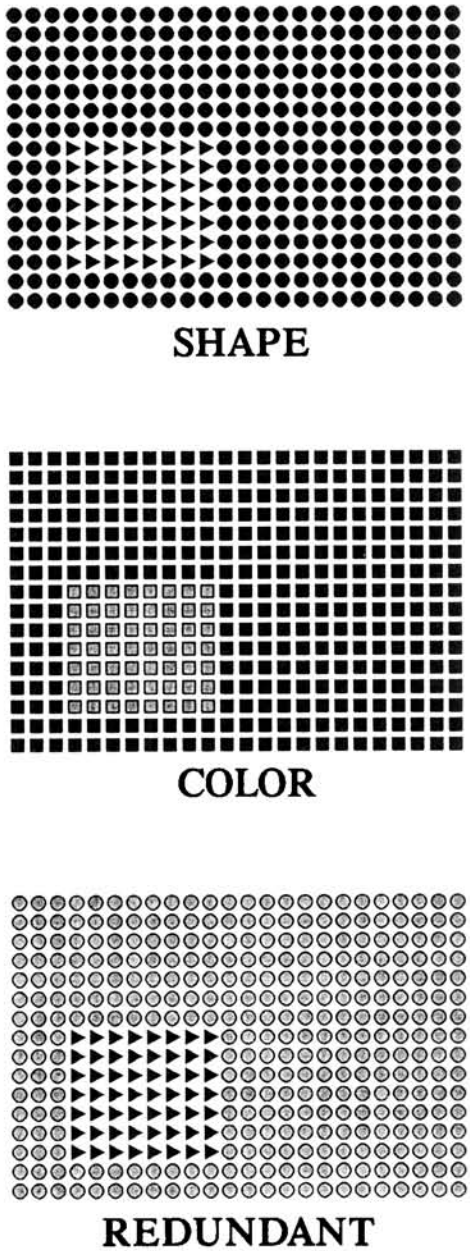
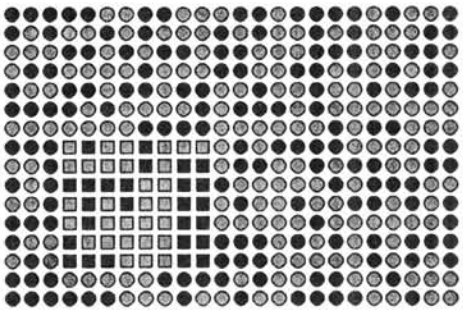
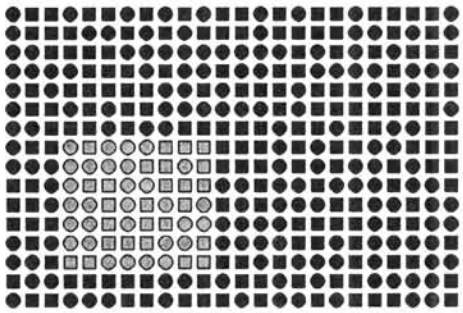


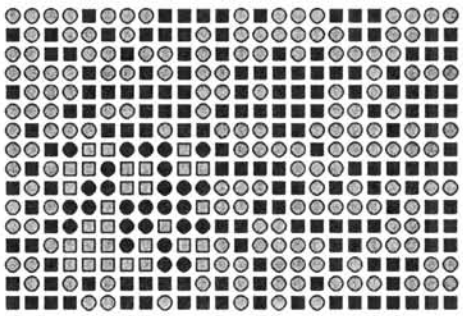
Figure 1. Representative examples of the baseline displays tested in every third session of Experiment 1. (The labels under each stimulus indicate the relevant dimension used to form the target and distractor regions of each display. The colors of the elements are shown as different shades of gray. Different types of elements indicate the basic variety of the stimuli tested. The contours around the individual elements are for illustration and were not part of the actual displays. The location of the interior target region is the same in all three examples but was randomly positioned on every trial during the experiment.)



FEATURE - SHAPE



FEATURE - COLOR



DOUBLE CONJUNCTIVE

Figure 2. Representative examples of the three test displays examined in Experiment 1. (These displays are composed from four elements composed from two shapes [square and circle] and two colors [depicted as different shades of gray]. Feature-color and feature-shape labels refer to displays with regions grouped according to each of these dimensions. Double conjunctive displays were made from combinations of the same elements but designed so that both dimensions were relevant. The contours around the individual elements are for illustration and were not part of the actual displays. The location of the interior target region is the same in all three examples but was randomly positioned on every trial during the experiment.)

conjunctive displays than with feature displays. This is because given the same period of time, less information about the location of the conjunctive target should have accrued due to its theoretically slower rate of processing.

These three display conditions were tested in sessions that alternated every third day with sessions that tested baseline displays (see Figure 1). These baseline sessions were simply the continuation of the daily procedures used before the experiment and were used to test color, shape, and redundant-texture stimuli (see Figure 1). The baseline sessions were included for several reasons. The first was to detect any changes in performance of the basic task caused by the introduction of the new display types. The second was to compare performance directly with the baseline and feature displays. This comparison reveals how the homogeneous and heterogeneous variation of the irrelevant dimension in color- and shape-relevant displays influences avian target detection. The resulting information is useful in determining whether these dimensions are being separately processed by the animals (e.g., Garner, 1974; Treisman, 1988).

Before continuing, a brief note on nomenclature is in order. Two slightly different conventions for generating conjunctive relations were used in the two experiments that are described. The method used to generate the conjunctive displays of Experiment 1 is hereafter referred to as producing *double conjunctive* displays. This is because two different conjunctive relations were produced simultaneously by the multiple elements used to form the regions of these stimuli (This same display type was labeled *disjunctive* in Cook, 1992b). In Experiment 2, I tested another form of conjunctive display that involved only one such relation, hereafter designated as *single conjunctive* displays. These separate labels help to distinguish between the different physical arrangements of these two types of test displays–a factor that may have been critical for the animals—while emphasizing the underlying similarity in their presumed information-processing requirements, at least as previously established with humans.

Method

Subjects. Four highly experienced White Carneaux pigeons were tested. They had been tested daily in texture discrimination tasks for several months before the experiment (>25,000 trials; see Cook, 1992a). The birds were maintained at 80% of their free-feeding weights during testing and had free access to water and grit in their home cages.

Apparatus. A flat-black plywood chamber (36 cm wide × 32 cm deep × 38 cm high) held the pigeons in front of a black plexiglas front panel (36 cm wide × 38 cm high). A 28-V houselight (No. 1812) was located in the center of the ceiling and was illuminated at all times, except when an incorrect response was made. A food hopper was located in the middle of the front panel, and the hopper's access hole was flush with the chamber floor. A Multisync II color monitor (NEC, Wooddale, IL) was located immediately behind the front panel and was visible through a 26 × 18 cm glass window. The bottom edge of this window was 20 cm above the chamber floor.

All experimental events were controlled and recorded with an AT-class microcomputer. All stimuli were generated by computer and presented directly to the pigeons on the color monitor. Stimulus generation and event programming were executed using QuickBasic (Microsoft, Redmond, WA) and a separate graphics library (Hydrex Graphics, Houston, TX). Computer-controlled relays (Metrabyte, Taunton, MA) governed the operation of the hopper and houselight. A VEGA Deluxe color video card (Video-7, Milpitas, CA) controlled the monitor in the enhanced graphics mode (EGA; 640 × 350 pixels;

all coordinates in this article follow a column × row format). The two display pages of this mode were used as "shutters" for the control of stimulus onset and offset.

Pecking responses to the monitor were detected by an infrared LED touchscreen(EMS Systems, Champaign, IL). This touchscreen was mounted behind a 40-mm ledge of plexiglas that spanned the inside edge of the viewing window. The resolution of the touchscreen was 96 × 48 spatial locations. A *peck* was defined as the penetration of and withdrawal from the LED matrix by the beak.

Stimulus generation. Texture displays were 18 × 12 cm and consisted of 384 colored shape elements arranged in a 24 × 16 array at 0.75-cm intervals. Individual elements were between 3 to 6 mm depending on their shape. The target region consisted of an 8 × 7 block of elements and was randomly located on every trial at one of 144 locations within the entire array. Chance performance was previously determined to be 38% correct for this particular task (Cook, 1992a, 1992b).

At the start of the experiment, the birds were performing texture discriminations of randomly placed targets composed from a pool of 64 elements. These elements were formed by the pairwise combination of eight colors (blue, red, green, cyan, yellow, white, purple, and brown) and eight shapes (U, T, square, triangle, chevron, double dots, circle, and arc, see Figure 2 in Cook, 1992a). The color and shape properties for all displays were generated using the *random trial composition* procedure. In this procedure, a display's elements are chosen completely at random and then arranged according to the configural requirements of the display type designated for testing on that trial.

Three types of baseline displays were generated. For *color* trials, the target and distractor elements differed in color but not in shape. For *shape* trials, the target and distractor elements differed in shape but not in color. For *redundant* trials, the target elements and distractor elements differed in both color and shape.

Three types of test displays were generated. Four elements consisting of the pairwise combination of randomly selected shape and color values (e.g., green square, green circle, red square, and red circle) were used to compose the three different display organizations. For the feature–shape displays, the elements of the target and distractor regions were grouped according to shape (e.g., green and red squares embedded within red and green circles). For the feature–color displays, the elements of the target and distractor regions were grouped according to color (e.g., red squares and circles embedded within green squares and circles). For double conjunctive displays, the elements of the target and distractor regions were grouped in a manner that crossed their color and shape properties (e.g., green circles and red squared embedded within green squares and red circles). The mixture and locations of the two elements composing each region of these three display types were randomly determined for each trial. As a result, the specific repetition of any test display occurred rarely, if at all.

Discrimination-testing procedures. Each texture discrimination trial began with a peck to a circular white ready signal (5 cm in diameter, EGA No. 63) in the center of the viewing area. This response darkened the computer screen for 0.4 s and was followed by presentation of a texture display. If the pigeon pecked five times at the target region, the texture display was turned off, and the hopper was raised for 2.5 s. If the five pecks were to the distractor region, the texture display was turned off and the houselight was extinguished for 15 s. Pecks to the target region and the one row and column of distractor elements adjacent to this area were considered to be target-directed responses. A 5-s intertrial interval (ITI) followed either trial outcome. The accuracy, time, and spatial location of all pecks were recorded.

The experiment consisted of 12 baseline and 24 test sessions. Baseline sessions used the three baseline display types and consisted of forty 5-trial blocks (200 total trials). Each of the 5-trial blocks consisted of two color, two shape, and one redundant texture discrimination trial, with their order of testing randomized. Test sessions examining the feature and conjunctive displays consisted of sixty 3-trial blocks (180 total trials). Each 3-trial block was composed of a feature-color, feature-shape, and double conjunctive texture discrimination trial. Their order of testing within each block was randomized. Two test sessions were conducted on consecutive days. A baseline session was conducted every third day. For purposes of statistical analysis, the baseline and test sessions were grouped in blocks of three baseline and six test sessions respectively. This resulted in a total of four blocks for each type of session.

Results

Feature and double conjunctive displays. The results of the first experiment indicate that feature displays supported higher levels of target detection accuracy than did the conjunctive displays in all 4 pigeons. There were no systematic differences in first-peck RTs to the two types of displays.

Accuracy over the four blocks of testing for the two test conditions is displayed in the upper panel of Figure 3. The mean accuracy for the 4 pigeons was 65.3% for the feature

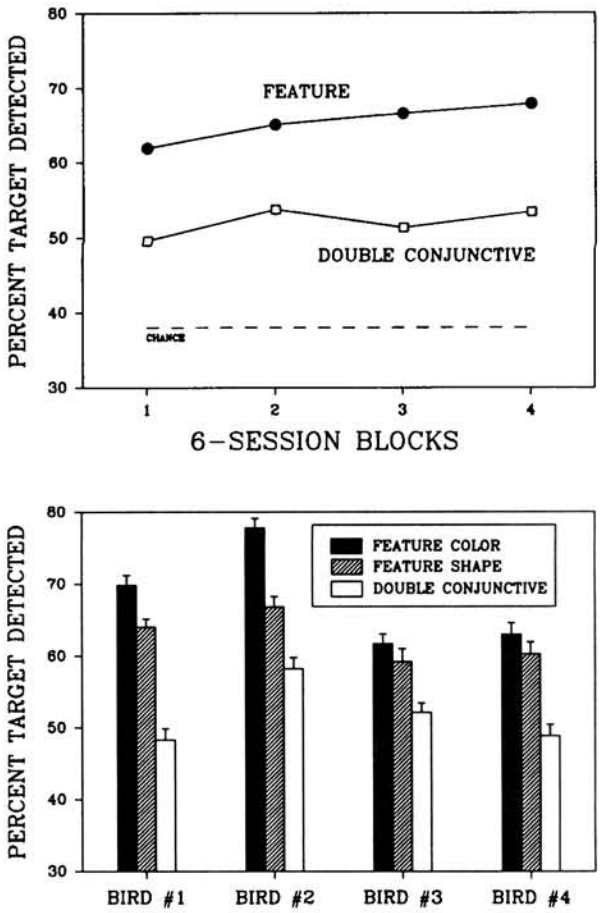


Figure 3. Mean target-detection accuracies for the 4 pigeons in the feature (color and shape combined) and double conjunctive conditions across the four blocks of Experiment 1 (top panel) and for the individual pigeons over the entire experiment for each of the three display types (bottom panel). (The condition labels refer to the stimulus displays depicted in Figure 2.)

displays and 52.0% for the conjunctive displays. Unless otherwise noted, all subsequently described statistical tests used a significance level of $p \leq .05$. A repeated measures analysis of variance (ANOVA) with Display Type (feature vs. conjunctive) × Six-Session Blocks confirmed that the accuracy difference between the two display types was significant, $F(1, 3) = 39.34$. Accuracy significantly improved over the four blocks, $F(3, 9) = 4.18$, but this improvement did not significantly interact with display type differences, $F(3, 9) = 1.68$. An identical analysis of RT revealed no significant differences between the feature (RT = 435 ms) and conjunctive (RT = 447 ms) display types, $F(1, 3) = 2.02$ or their interaction over blocks, $F(3, 9) < 1$.

The lower panel of Figure 3 displays each pigeon's mean accuracy with the test displays. Three repeated measures ANOVAs (Display Type × Six-Session Blocks) were used to compare the feature–color, feature–shape, and conjunctive displays in a pairwise manner. Results revealed that accuracy in both the feature–color condition (68.1%) and feature–shape condition (62.5%) were significantly higher than in the conjunctive condition, $F(1, 3) = 33.93$, and $F(1, 3) = 33.43$. The difference between the two feature conditions was not significant, $F(1, 3) = 7.66$. None of these effects significantly changed over blocks.

Baseline displays. Overall accuracy with the color (74.3%), shape (66.8%), and redundant (78.3%) baseline displays was higher than with the test displays. Pairwise repeated measures ANOVAs comparing the three baseline conditions (Baseline Display Type × Three-Session Blocks) revealed that both color, $F(1, 3) = 20.66$, and redundant, $F(1, 3) = 19.15$, displays supported significantly higher accuracy than shape displays and that color and redundant displays did not significantly differ, $F(1, 3) = 6.04$.

Color and shape baseline accuracy were then compared with feature–color and feature–shape accuracy to investigate how variation in the irrelevant dimension influenced target detection. During Block 1, accuracy with the two baseline display types (71.2%) and the two feature-display types (62%) was significantly different, $F(1, 3) = 21.50$. By Block 4, however, the difference between baseline (68.2%) and feature (67.9%) display accuracy had disappeared, $F(1, 3) < 1$.

Discussion

The most important finding in Experiment 1 was the difference in performance with the feature and double conjunctive displays. Target-detection accuracy was better when the elements of the target and distractor regions were grouped by their color or shape properties than when they were grouped by a mixture of these properties that made the joint status of both dimensions relevant. The pigeons thus showed a pattern of results analogous to those found with humans tested with similar displays (Treisman & Gelade, 1980, Experiment 5).

Humans and pigeons were dissimilar in that the differences produced by the test displays were manifested in different response measures. For the pigeons the difference was reflected in choice accuracy, whereas for humans it was reflected in sorting time. In the case of the present experiment, it is possible that the pigeons were trading accuracy for response speed. The birds responded very quickly to all texture displays (<500 ms), and there were no significant RT differences between conditions. Given the rapid nature of their responding, and the assumption that the conjunctive displays take longer to accurately process than the feature displays, it is not surprising that accuracy was poorer with the conjunctive displays.

In Experiment 1, I also found that the responses of the pigeons to the variation of the irrelevant color or shape properties in the feature displays shifted over the course of the experiment. It appears that the variation in the irrelevant dimension of the feature displays did disrupt performance on the relevant dimension initially. With continued testing this effect disappeared, however, and overall choice accuracy with the heterogeneous feature displays and the homogeneous baseline displays converged to the same level. Treisman (1988) reported an analogous form of this latter result for humans tested with heterogeneous and homogeneous displays in visual search experiments.

The failure of irrelevant information to interfere with the processing of the relevant component of multidimensional displays is considered to be one of the characteristic properties of independent, or separable, stimulus dimensions (Garner, 1974). If so, the current results suggest that the color and shape properties of these textured displays were being separately and independently processed by pigeons, at least in the latter stages of the experiment. These results converge with those of other experiments that have tested the responses of pigeons to line orientation–color compound stimuli in different types of visual discriminations. These, too, have suggested that the dimensional properties of such compound stimuli can be independently processed by pigeons (Brown, Cook, Lamb, & Riley, 1984; Cook, Riley, & Brown, 1992; Leith & Maki, 1975).

All in all, the analogous response of pigeons and humans to feature and conjunctive arrangements of multidimensional displays suggests these dissimilar species may share functionally similar mechanisms for processing textured dimensional information. For humans, results similar to those found in Experiment 1 have suggested a variety of two-stage explanations (Cave & Wolfe, 1990; Hoffman, 1979; Treisman & Gelade, 1980; Treisman & Sato, 1990). The results of Experiment 1 suggest that these explanations may be of use in understanding the visual processing of dimensional information by birds as well.

Experiment 2

The results of Experiment 1 suggest important similarities in the mechanisms underlying the grouping of visual information in humans and pigeons. The objective of Experiment 2 was to broaden and strengthen this conclusion. Toward this end, pigeons and human subjects were tested with both the previous test displays and a new variation of these displays. The human subjects were tested with the identical displays and procedures as the pigeons. This was done to confirm that these displays were capable of reproducing the effects previously established for humans. More important, a new and

different variation of the feature and conjunctive operations was tested with the pigeons. This was done to ensure that the previous differences were not due to the specific nature of the displays tested in Experiment 1 but instead represented a more general processing effect directly related to dimensional arrangement. Figure 4 presents illustrative examples of the new feature–color, feature–shape and single conjunctive displays examined in Experiment 2. These new feature and conjunctive displays are more like those typically used in visual search experiments with humans (Quinlan & Humphreys, 1987; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). The rules for generating the new displays of Experiment 2 were the same as those used previously by Treisman and Gelade (1980, Experiment 1), but the displays were modified into textured displays more suited to the visual discrimination learned and performed by these pigeons. These new feature and single conjunctive displays used only a single element type to form the target region and a random mixture of two element types to form the surrounding distractor region.

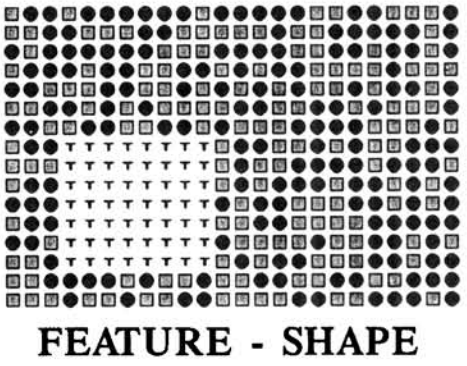


Figure 4. Representative examples of the three test displays added in Experiment 2. (The feature-color and feature-shape labels refer to displays with target regions defined by the addition of a third feature unique to that dimension. The single conjunctive displays were made from combinations of values that were shared with the distractor elements and that made both dimensions relevant. Differences in colors are depicted as different shades of gray. The contours around the individual elements are for illustration and were not part of the actual displays.)

For the feature–shape displays, the elements of the target region were made by randomly selecting a third shape, different from either of the ones used for the distractor elements, and combining the third shape with one of the two colors used to form the distractor elements (e.g., green *T* in red squares and green circles). Likewise for the feature–color displays, the elements of the target region were made with a randomly selected third color in combination with one of the two shapes forming the distractor elements (e.g., blue circles embedded within red squares and green circles). For the single conjunctive displays, the elements of the target region were made by conjunctively combining the color from one of the distractor elements with the shape from the other (e.g., red circles embedded within red squares and green circles). These operations thus produce the same background of distractors for all three display types, and differences between displays result solely from the dimensional relations of their respective target regions.

Each session of Experiment 2 tested six different stimulus conditions. Half of these were the three new displays just described, and the remaining half were the feature and double conjunctive displays tested in Experiment 1. The continued testing of the previous display types was conducted to examine what effect experience might have on the feature–conjunctive accuracy difference found in Experiment 1.

Method

Subjects and apparatus. The same 4 pigeons were tested. They were maintained the same as in Experiment 1. Eight adult humans were also tested. All reported having normal or normal-corrected acuity and no color blindness. The apparatus described in Experiment 1 was used to test both species.

Stimulus generation. Six display types were generated and tested in Experiment 2. The feature and double conjunctive displays from Experiment 1 were generated in the same way as previously described. The new feature–color, feature–shape, and single conjunctive displays were generated in the following manner.

For all three new displays, the distractor region was formed by randomly mixing two randomly constructed elements. The color and shape properties of these distractor elements were randomly selected without replacement from the pool of color and shape values. In the feature–shape displays, the elements of the target region were made by randomly selecting a third shape, different from those of the distractor elements, and combining it with one of the two colors used in forming the distractor region. In the feature–color displays, the

elements of the target region were made by randomly selecting a third color and combining it with one of the two shapes used to form the distractor elements. In the single conjunctive displays, the elements of the target region were made using a color and a shape selected at random from the two distractor elements.

Pigeon discrimination-testing procedures. Individual trials were conducted in the same way as in Experiment 1. The accuracy, time, and spatial location of all pecks were recorded. Each test session consisted of 40 blocks of 6 trials (240 total trials/session). Each 6-trial block consisted of one presentation of each of the six display conditions, with their order of test randomized for each 6-trial block.

Finally, the size of the target region was alternated between sessions. Birds were tested with an 8 × 7 target region for one session and then with a 6 × 5 target region in the next session. Fifty-six total sessions were conducted, 28 with each target size. For the purpose of statistical analysis, the 28 sessions with each target size were grouped into 7-session blocks. As with Experiment 1, this resulted in a total of four blocks for each type of session.

Human discrimination-testing procedures. The human subjects were tested with the same apparatus except that the operant chamber was removed from the front panel. Humans sat approximately 60 cm from the front display panel and responded to the displays with the forefinger of their preferred hand. They were informed that it was an RT experiment and instructed to respond as quickly and accurately as possible. After 5 to 10 warm-up trials familiarizing the subjects with the stimuli and response requirements of the task, such as returning their hands to the same starting location for each trial, the same computer program used to conduct the experimental sessions with the pigeons was executed. Each subject participated in one 240-trial session and was tested with only the 8 × 7 target size. All temporal parameters were the same, except that the hopper was only briefly (0.2 s) illuminated for correct responses.

Results

Humans. The results for the humans were as expected given the published research. Accuracy was uniformly high (>98.0%), except with the double conjunctive displays (92.8%), and the differences between the displays were manifested in terms of RT. As anticipated, the subjects found and touched the target region of the double conjunctive displays (1,149 ms) significantly more slowly than its corresponding feature displays (feature–color = 435 ms; feature–shape = 440 ms), $F(1, 7) = 151.23$. Likewise, for the three new displays, subjects touched the target region of the single conjunctive displays (501 ms) significantly more slowly than its corresponding feature displays (feature–color = 434 ms; feature–shape = 424 ms), $F(1, 7) = 14.92$.

Pigeons. Overall, target-detection accuracy with the 8 × 7 targets (66.7%) was better than with the smaller 6 × 5 targets (42.1%). Analyses of both target sizes revealed no differential effect on display-type differences. Because of this similarity and the superior overall performance with the larger target size, only those data are described further.

For the pigeons, the four feature displays supported significantly higher levels of target-detection accuracy than the two types of conjunctive displays. Their combined target detection accuracy (66.7%) was significantly higher than with the single and double conjunctive conditions (59.2%), $F(1, 3) = 33.67$, Display Type × Seven-Session Blocks repeated measures ANOVA. Accuracy significantly improved over blocks, $F(3, 9) = 21.46$, but again did not interact with the different display types, $F(3, 9) < 1$. As in Experiment 1, no significant RT differences were found between the displays. Identical analyses of first-peck RT found no significant differences between the four feature displays (454 ms) and the two conjunctive displays (485 ms), $F(1, 3) = 1.91$.

Feature and double conjunctive displays only. The results for these display types were essentially identical to those found in Experiment 1. The upper panel of Figure 5 displays the mean feature and double conjunctive accuracies for the four blocks of testing in the second experiment. The two feature displays (66.3%) yielded a significantly higher level of target-detection accuracy than the conjunctive displays (57.2%), $F(1, 3) = 39.88$. Accuracy significantly improved over the four 7-session blocks, $F(3, 9) = 5.0$, but did not interact with the feature–conjunctive accuracy difference, $F(3, 9) = 1.46$. Again, analysis of RTs found no significant differences between the feature conditions (RT = 447 ms) and the double conjunctive (RT = 504 ms) conditions, $F(1, 3) = 2.50$.

Results for each individual bird are presented in the lower panel of Figure 5. Three pairwise ANOVAs (Display Type ×

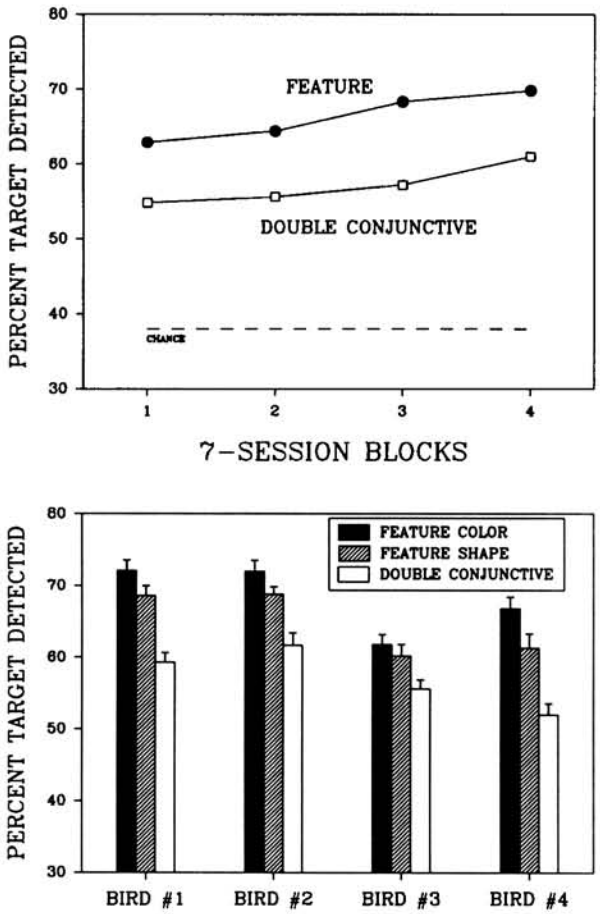


Figure 5. Mean target-detection accuracies for the 4 pigeons in the feature (color and shape combined) and double conjunctive conditions across the four blocks of Experiment 2 (top panel) and for the individual pigeons over the entire experiment for each of the three display types (bottom panel). (The condition labels refer to the stimulus displays depicted in Figure 2.)

Seven-Session Blocks) were used to compare accuracy among the three display conditions. Target-detection accuracy was significantly higher with the feature–color display (68.3%), $F(1, 3) = 34.25$, and the feature–shape display (64.5%), $F(1, 3) = 49.38$, than with double conjunctive displays (57.1%). The difference between the two feature conditions was also significant, $F(1, 3) = 17.83$.

Feature and single conjunctive displays only. Results for the new feature and single conjunctive displays essentially mirrored those found above, with display-type differences again manifested as accuracy and not RT differences. The upper panel of Figure 6 displays the mean feature and single conjunctive accuracies over the four blocks of testing in Experiment 2. Target-detection accuracy with the two feature displays (67.1%) was significantly better than with the single conjunctive display (61.1%), $F(1, 3) = 21.73$. Accuracy significantly improved over the four 7-session blocks, $F(3, 9) = 20.02$, but again did not interact with the difference in feature–conjunctive accuracy, $F(3, 9) = 1.07$. Analyses of RT found no significant display differences (feature = 462 ms; single conjunctive = 468 ms), $F(1, 3) < 1$.

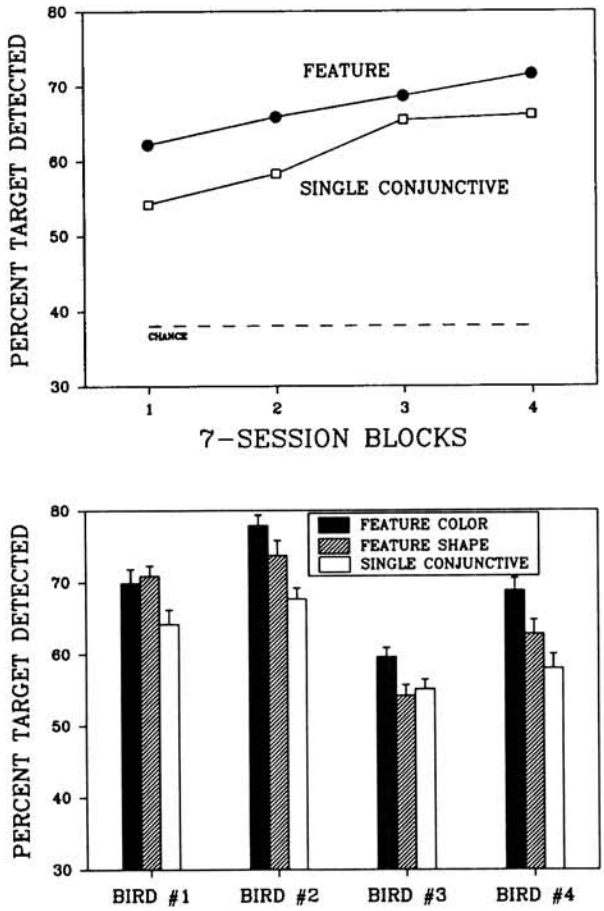


Figure 6. Mean target-detection accuracies for the 4 pigeons in the feature (color and shape combined) and single conjunctive conditions across the four blocks of Experiment 2 (top panel) and for the individual pigeons over the entire experiment for each of the three display types (bottom panel). (The condition labels refer to the stimulus displays depicted in Figure 4.)

Results for each individual pigeon are presented in the lower panel of Figure 6. Three pairwise ANOVAs (Display Type × Seven-Session Blocks) revealed that target-detection accuracy was significantly higher with feature–color displays (68.9%) than with conjunctive displays (61.1%), $F(1, 3) = 33.86$). The difference between the two feature conditions was not significant, $F(1, 3) = 6.65$. The comparison of the feature–shape (65.4%) and conjunctive conditions was also not significant $F(1, 3) = 7.64$, $p < .07$, although 3 of the 4 pigeons were more accurate with feature–shape than with conjunctive displays. Only in this particular case were the results with the 6×5 targets different from those described above, as accuracy in the feature–shape condition was significantly higher than in the single conjunctive condition, $F(1, 3) = 14.43$.

Discussion

The most important finding in Experiment 2 was that both pigeons' and humans' texture discrimination was poorer with both kinds of conjunctive displays than with their corresponding feature displays. As expected, the humans manifested this difference in terms of search RT. This result indicates that the previously reported effects for these types of displays were indeed being reproduced with the present stimulus configurations. For the pigeons, these display type differences were once again manifested in terms of target-detection accuracy. Thus, Experiment 2 corroborates and replicates the findings of Experiment 1 and strengthens the basic findings by extending them to new examples of feature and conjunctive displays. These new displays were more analogous to the types of displays most often tested with humans and were organized in a physically different manner from those of Experiment 1. The similar response of the pigeons to these two distinct variations of feature and conjunctive displays thus reflects a general effect of dimensional arrangement on avian information processing and not an effect tied specifically to a particular form of display.

The pigeons continued to respond quickly (400–500 ms) to the presentation of all displays and as a result showed no reliable RT differences between the different conditions. Contrary to the findings for the pigeons, and presumably in response to the experimenter's instructions, the humans spent additional time looking for the conjunctive targets. Thus, the longer response times to these displays reflects the additional processing steps apparently required to locate targets defined in this way (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Treisman & Sato 1990; Watt, 1988).

For both the humans and pigeons, the differences between the feature and double conjunctive displays were greater than the differences between the feature and single conjunctive displays. This was probably the result of several ancillary properties related to the texture-modified configuration of the latter displays. As the target region of these displays was formed by the repetition on only one type of element, it was more homogeneous in nature compared with its surrounding distractor region than was the case for the double conjunctive displays. This target region uniformity in turn assisted in producing emergent boundaries between the target and distractor regions of these configurations. Both of these addi-

tional factors may have helped both the pigeons and humans to locate the targets in single conjunctive conditions, independent of dimensional organization. The randomized mixture of multiple elements in the double conjunctive displays eliminated both of these emergent objectlike factors from aiding in target detection. These speculations are fostered in part by previous results suggesting that the regional discontinuities or edges of textured displays may be important in the discrimination of such stimuli by pigeons (Cook, 1992b) and by other reports showing that pigeons are sensitive to the relative mixture or heterogeneity of color and shapes in multielement arrays (Honig, 1991).

Lastly, the results of Experiment 2 suggest that the difference between feature and conjunctive display types for pigeons is neither due to nor easily influenced by experience. This is particularly significant given the pigeons' previous training and experience with the baseline color and shape texture discrimination. One possible explanation for the initial difference between the feature and double conjunctive displays was that the former looked more like the pigeons' original training displays than the latter. This does not seem to be case, because even after 10,000 trials with these conditions, the difference in accuracy between feature and double conjunctive displays persisted. Although there was a slight decrease in the absolute size of the difference in Experiment 2, this change is somewhat mitigated by the slight (but nonsignificant) increase in search RT between experiments for the double conjunctive displays (from 447 to 504 ms). These "longer" RTs may be a very weak indication that the pigeons may have started to compensate for the difficulty of these displays by taking slightly longer to process them. Regardless, the chronic nature of the effect over the 80 combined sessions of Experiments 1 and 2 indicates that experience was not the critical factor in producing this difference.

General Discussion

These experiments demonstrate that visual texture discriminations by pigeons are strongly influenced by the dimensional organization of a display's regional components. The results overall are directly analogous to those reported for humans tested with conceptually similar stimuli in visual-search and texture-segregation experiments (Treisman & Gelade, 1980) and those results replicated in Experiment 2 with the stimuli described earlier.

Both species were significantly better when the target and distractor regions were uniquely different in either color or shape properties than when these regions were formed by conjunctions of these dimensional properties. Both species found the double conjunctive organization more difficult to process than the single conjunctive combination. Finally, during the latter stages of Experiment 1, variation in the irrelevant dimension of a feature display produced little or no interference with the concurrent discrimination of the relevant dimension by the pigeons. A similar result has been reported for humans (Treisman, 1988). These similarities suggest that both species have functionally comparable *underlying visual mechanisms* mediating the perception of these textured displays and their dimensional properties.

For results with humans, the preferred explanations for these kinds of stimulus effects have generally converged toward a group of theories that propose that two processing stages are involved in the perception of multidimensional displays. (Cave & Wolfe, 1990; Duncan & Humphreys, 1989; Hoffman, 1979; Treisman & Sato 1990; Watt, 1988). The first is an early parallel preattentive visual stage, which independently registers information about the separable dimensions or features present in the display. This dimensional information can then be used to group and segregate features of the array into perceptual regions (Beck et al., 1983; Grossberg & Mingolla, 1985; Julesz, 1981). A second stage of processing then examines the output of the first to determine the target's location. If the feature differences detected by the first stage are large or unique, as is the case in the feature displays, the second stage can rapidly determine the target's location. If the regional differences are small or share too many common features, then the second stage of processing takes longer as smaller portions of the display have to be thoroughly examined to accurately locate the target. The extensive use of this secondary, serial-like process with the conjunctive displays is presumed to be responsible for the substantial increases in human search RTs in these cases.

The current results suggest that the mechanisms underlying the perception of these textured stimuli may be similarly organized in pigeons. For instance, the pigeons accurately perceived and responded to any display that could be grouped by either its color or shape properties, but if stimuli were organized so that the joint status of both dimensions was required, pigeons' accuracy suffered. These results suggest that the early visual processes of pigeons can also rapidly segregate textured stimuli into distinct regions by grouping similar features within separate dimensions. This conclusion is consistent with the results of other recent experiments examining the acquisition and transfer of color and shape texture discriminations by pigeons (Cook, 1992a).

Because these display effects were manifested in terms of response accuracy rather than RT, however, the present results are silent about the role or presence of any secondary attentional or serial mechanism in avian texture perception. No systematic display differences emerged on a between-subjects basis. Two pigeons did show systematically longer RTs to the conjunctive displays but were never compensated for this with significantly higher levels of accuracy. Two conclusions are possible. The first is that the secondary stages of the search processes proposed for humans are not present in pigeons. Thus, the pigeons were responding to all test stimuli based only on the output of their early preattentive grouping of the displays. The second possibility is that such attentional processes are present but are not used effectively in the case of conjunctive displays, perhaps because of the pigeons' impulsive responding to all displays during the course of these experiments. The latter seems a more likely explanation.

For instance, in other types of visual search experiments with pigeons, the duration of target search has been shown to be influenced by the number of distractors present in the display (Allan & Blough, 1989; Blough, D. S., 1977, 1979; Blough, P. M., 1984). This indicates that serial-like, element-

by-element searches of multielement displays occur under certain circumstances. Because the present texture discrimination procedure is a form of visual-search task, it seems likely that the effects of dimensional organization found in these experiments could be replicated in a visual-search procedure that used only a single element as a target, rather than a whole region. Future research testing pigeons in such tasks could provide important data concerning the presence or absence and the role of any secondary attentional-like search mechanisms in birds.

Overall, the present experiments provide some of the strongest evidence yet that the early perceptual mechanisms of mammals and birds are functionally similar, despite the large differences in the size and neural organization of their respective visual systems (Donovan, 1978; Pearson, 1972). The present results suggest that the early visual mechanisms for initially encoding, grouping, and combining textured dimensional information are directly comparable in both species, and that for pigeons and humans the grouping of visual information occurs within, and not between, perceptual dimensions.

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