

**Perspectives on Fundamental
Processes in Intellectual Functioning
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**PROCESSES OF VISUAL
COGNITION IN THE PIGEON***

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After many years of putting it off, you finally have made it to the Galapagos Islands, the birthplace of modern evolutionary thought. Scrambling over the rocky landscape a number of clearly related birds catch your eye. Upon more careful study, noting the distinctive shape of their beaks and where and how they feed, you begin to suspect they might be different species. One particular kind of bird working its way along the limb of a tree then grabs your attention, as it is holding a cactus spine in its beak. With this spine it begins to carefully probe into the tree, and to your ornithological delight, it soon pulls out an insect grub that is promptly consumed. Interestingly, this woodpecker finch, one of a group of 13 species known as Darwin's finches, has evolved in this isolated environment to fill much the same kind of niche as its woodlands namesake—but instead of relying on adaptations of

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its beak, it has done so by employing a rudimentary tool (Millikan & Bowman, 1967).

Such acts of seemingly "purposive" and "intelligent" animal behavior have stimulated thinking about the mental life of animals and its relation to our own thought processes since antiquity. The modern study of animal cognition begins with Darwin, who first seriously raised the notion that there was evolutionary continuity between the mental life of humans and animals (Darwin, 1872). From these beginnings, numerous questions have arose about the processes of animal behavior, many that are debated to this day. How are we to best explain the variety of organized and complex goal-directed behaviors observed in animals? Do they "reason" at all about the problems they face in daily survival? How do animals learn and change their behavior as a function of this daily experience? Are there species differences among animals in any of these matters? If so, in what ways are they different from one another and why? Do they share a mental life that is at all related to the one we seem to experience? What role might consciousness and language, two quintessential elements of human intelligent behavior, play in the mental life of animals? Just from this brief sampling, we hope it is clear that the natural behavior of animals generates a vast host of intriguing comparative questions and puzzles ripe for psychological investigation.

Despite the seminal importance of studies of animal thought and intelligence to the early development of psychology and our thinking about human behavior (Hull, 1943; Kohler, 1925; Pavlov, 1927; Skinner, 1938; Thorndike, 1911; Watson, 1925), the majority of modern psychology's textbooks, courses, and journals treat animal and human cognitive functioning as essentially separate unrelated enterprises, each relegated to its own chapter or conference session. One reason for this split surely harkens back in one form or another to earlier philosophical and religious dogma concerning the *Scala Naturae* and the idea of the qualitative and hierarchical superiority of humans to all other living things (Hodos & Campbell, 1969). A more recent factor in this split was the information processing and cognitive revolution of the 1950s and 1960s on the study of human behavior (Gardner, 1985). This revolution completely changed the direction and study of human learning, memory, and thought; but the study of animal learning retained its historical concentration on associative analyses of behavior—perhaps reflecting its long history of not inferring unnecessarily complex cognitive mechanisms when simpler ones will do (Morgan, 1984). With the independent growth of these different theoretical orientations, the experimental tools and procedures used to study cognitive psychology in humans and classical and operant learning in animals also diverged. This further complicated any direct comparison of results from humans and animals, and additionally solidified their division. Collectively, such considerations caused the modern study of human thought to become increasingly separate from the study of animal thought, even growing to the point that some even began to dismiss the study of animals as potentially irrelevant to understanding human behavior (e.g., Lachman, Lachman, & Butterfield, 1979). Nothing could be further from the truth.

Consider the essential question regarding the origins and evolution of cognitive processes and intelligent behavior. Clearly language and language-related behavior, to consider one of any number of possible examples in this domain, did not spring fully formed at the dawn of hominid evolution, for instance. It must have emerged from cognitive processes already present and operating in our primate ancestors. What these cognitive precursors were and how they changed and developed over the last few million years must have undoubtedly influenced our contemporary capacity for language and its associated symbolic processes. It is the behavioral examination and comparison of living animals (humans being no exception to this latter classification) that remains our only real tool for reconstructing the evolution of behavior (Brown, 1975). Although a matter of continued debate, some animals now appear capable of using and understanding aspects of human-like symbolic language (Gardner, Gardner, & Van Cantfort, 1989; Greenfield & Savage-Rumbaugh, 1990; Herman, 1987; Pepperberg, 1990). The study of such animals, in conjunction with the study of natural communication systems and the intelligent behaviors of animals without such language capacities, will hopefully shed light on the origins of language and its contribution to thought (e.g., Dennett, 1996; Donald, 1991; Premack, 1983; Weiskrantz, 1988). In addition, to these types of evolutionary questions, the study of animals will remain one of the very best avenues for experimentally studying brain-behavior relations in fine detail, despite the exciting recent advances in the neural imaging of the human brain. Furthermore, the study of animals also remains the best vehicle for dissecting the relative contribution of experience and genetics to cognitive functioning and intelligent behavior, as we can specifically control their past experience and ever increasingly the structure of their DNA. As such, we believe the current separation of the study of human and animal thought and behavior is an unfortunate and highly artificial division. The elimination of this divide and the future development of a true comparative cognitive psychology offers a unifying perspective for psychologists of many stripes, ranging not only from those interested in animal and adult human cognition, but including those focused on understanding the normal and atypical development of cognition in young children, the contributions of culture to cognition and behavior, or the tantalizing question of implementing artificial intelligence in computers.

Besides these comparative issues, other recent developments in the study of cognition in animals should also make this area once again of greater interest to researchers focused on human cognition. One of the primary catalysts for this is the delayed impact of the same cognitive revolution that earlier washed across the study of human learning and memory. The impact of this influence can be seen in recent shifts from an almost exclusive focus on learning and behavior to a much broader examination of cognitive processes in general (Cook, 1993b; Fetterman, 1996; Honig & Fetterman, 1992; Hulse, Fowler, & Honig, 1978; Roitblat, Bever, & Terrace, 1984; Wasserman, 1993; Zentall, 1993). Thus, besides its traditional focus on associative learning mechanisms, the modern study of animal cognition

has expanded its domain of investigation, increasingly focusing on issues like working and reference memory, rehearsal, imagery, visual perception, language-like behaviors, sequence production and learning, and concept learning. Coupled with the increasingly common questions about the mechanisms of cognition in humans and animals, there has also been an accompanying increase in the similarity of the procedures used to test these ideas. In particular, the development and increasing use of computer-based testing procedures for animals has resulted in a growing number of fruitful comparisons between human and animal cognition (e.g., Blough, 1977, 1985, 1993; Cook, 1992a, 1993a; Matsuzawa, 1990; Terrace, 1993; Wasserman, Kirkpatrick-Steger, Van Hamme, & Biederman, 1993; Wright, Cook, Rivera, Sands, & Delius, 1988; Wright, Santiago, Sands, Kendrick, & Cook, 1985).

It is this new approach that characterizes the program of comparative cognitive research outlined in this chapter. We have been interested in understanding the visual capabilities of one highly interesting non-mammalian species—the pigeon (*Columba livia*). Our goal is to understand the perceptual and decisional processes involved from the point when external visual information first impinges upon the animal to its final behavioral reaction to this information. By looking in detail at all aspects of how birds accomplish complex visual discriminations, we hope to uncover the cognitive and neural mechanisms employed by this remarkable class of visually-sophisticated animals, and to compare them with those mechanisms found in other animals, including humans.

THE COMPARATIVE STUDY OF AVIAN VISUAL COGNITION

Birds behave as if they visually experience an object-filled world. Their unerring avoidance of obstacles during flight, detection of small prey items, and pinpoint landings on small wind-blown limbs all point to a rich and accurate visual perception of their surrounding environment. Vision's unmistakable importance to birds is reflected in the substantial proportion of their compact brains devoted to visual processing and the huge relative size of their eyes (Donovan, 1978; Emmerton, 1983; Pearson, 1972; Zeigler & Bischof, 1993). Birds have also been subject to strong evolutionary pressure with respect to their size and weight, in large part due to the biomechanics of muscle-powered flight. In response to such pressure birds have evolved small visual and central nervous systems that appear to be efficient and powerful. This mixture of power and small size is extraordinary, and somewhat paradoxical given our current understanding of the computational difficulties of vision (Arbib & Hanson, 1987; Fischler & Firschein, 1987; Landy & Movshon, 1991). As a result, the study of avian visual cognition is a rich and immediately available source of information about perceptual and cognitive processes in a visually intelligent, highly autonomous, biological system, and a perfect complement to our growing knowledge about the processes of mammalian visual cognition.

The vast majority of birds, being primarily visual foragers, move about their world regularly searching for food. Whether looking for small invertebrates in the forest canopy or seeds among the leaf litter on the ground, many different kinds of objects are encountered, identified as food or not, and then either consumed or rejected. What are the visual and cognitive mechanisms involved in this complex visually-guided behavior? Are they at all the same as we employ when searching about the clutter of our desk for a pen or paper clip? For example, does this search behavior involve a combination of parallel and serial search processes? Is selective attention involved? Are the items birds encounter perceived and encoded as "objects?"

To get a handle on these and other related questions we have for the last few years been examining the perceptual/cognitive system of pigeons, focusing on their ability to discriminate different types of complex visual displays in texture discrimination and visual search tasks (Cook, 1992a, 1992b, 1992c, 1993a, 1993b; Cook, Cavoto, & Cavoto, 1995, 1996; Cook, Cavoto, Katz, & Cavoto, 1997; Cook, Katz, & Cavoto, 1997; Cook & Wixted, 1997). Visual textures are multidimensional, multi-element, hierarchical patterns in which distinct global regions are derived from the organization of smaller component elements (see Figure 1). These stimuli are tested in computerized operant chambers, where they are presented on high resolution color CRTs equipped with touchscreens that record the birds' reactions to these stimuli.

Texture stimuli have a rich history in the study of human visual perception. They have been used to study both the effortless and apparently preattentive perceptual grouping processes performed by our early visual system as well as the more time consuming deployment of attention over space (Beck, 1966, 1982; Julesz, 1975, 1981; Marr, 1982; Treisman & Gelade, 1980). The advantages of using such stimuli are that they allow the experimenter to have precise control over dimensional and spatial characteristics, while retaining sufficient complexity to make generalizations to the real world meaningful. Another important feature of our approach is that we take advantage of the computer's ability to flexibly generate large numbers of displays from a variety of different color and shape elements. This has allowed us to train and test the pigeons with far more stimuli than have been traditionally employed with animals. It is this mixture of precise control and moderate complexity, in conjunction with its well established foundations and connections to human visual perception, that has made using this class of stimuli so rewarding to study in pigeons.

One of our most commonly employed strategies for exploring texture discrimination and search has involved what we call the target localization task. In this task, each computer-generated texture stimulus presented to the bird contains a small *target* region, constructed from smaller individual elements. This target is then randomly located within a larger matrix of *distractor* elements that might contrast with the target in either color or shape. For example, a display might consist of an 8 × 7 block of blue triangles randomly embedded within a larger 24 × 16 region of

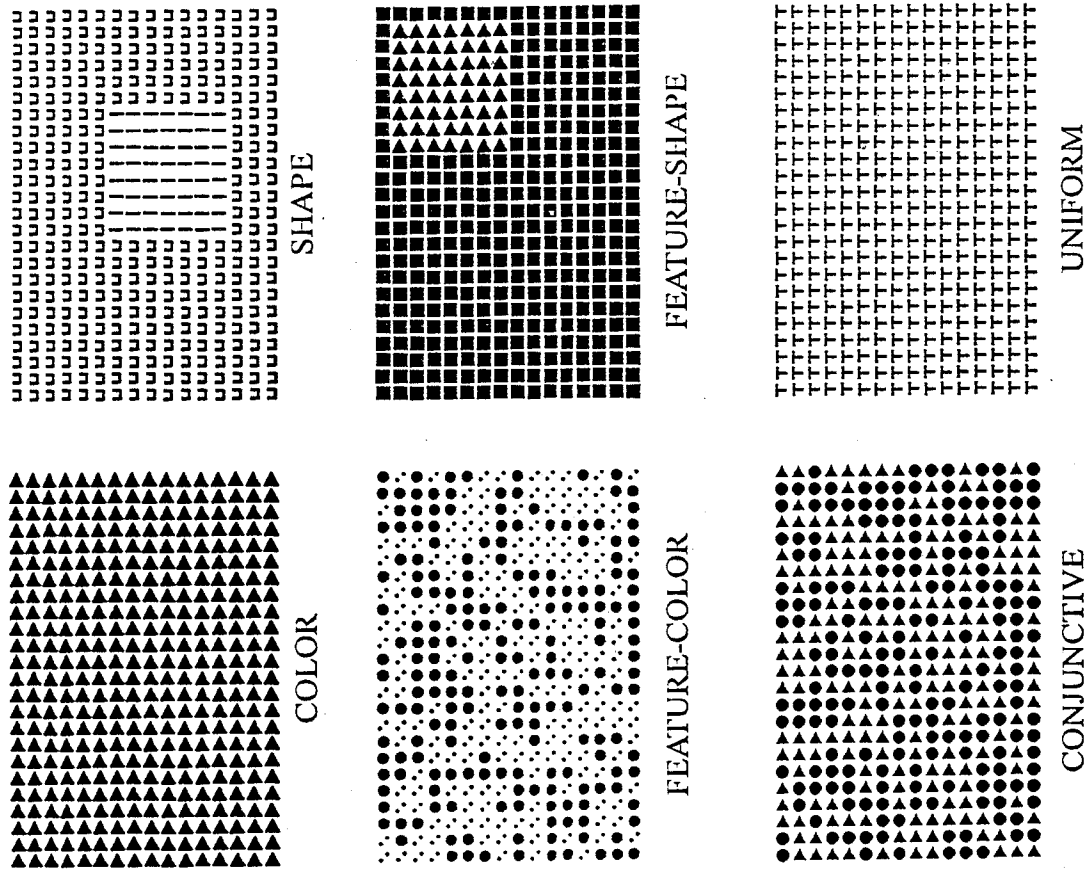


FIGURE 1. Examples of color, shape, feature-color, feature-shape, conjunctive, and uniform texture displays used in the various discrimination experiments discussed in this chapter.

red triangles, thus requiring a color discrimination of the display by the bird. The pigeons' task is to locate and peck at this odd target region in order to receive food reinforcement (e.g., five pecks to the target region produces food, five pecks to the distractors causes a brief timeout in the dark).

As with any search task, this target localization procedure requires the dynamic interaction between the birds' current perception of the stimulus and their working and reference memories of what is an appropriate "target" and/or "distractor." Figure 2 outlines a hypothesis about the organization and flow of information during a pigeon's performance of such a visual discrimination. In general three broad steps are needed for the pigeons to respond accurately. The first step involves the basic registration and perception of the display's current attributes. For the purpose of simplicity, this is labeled "stimulus input" in the diagram. The complexity and challenge of understanding the set of visual operations contained within this modest box should not be underestimated. Given a working perception of at least a portion of the display, the next step requires comparing this input with the contents of memory in order to establish whether a "target" is currently being viewed. If the

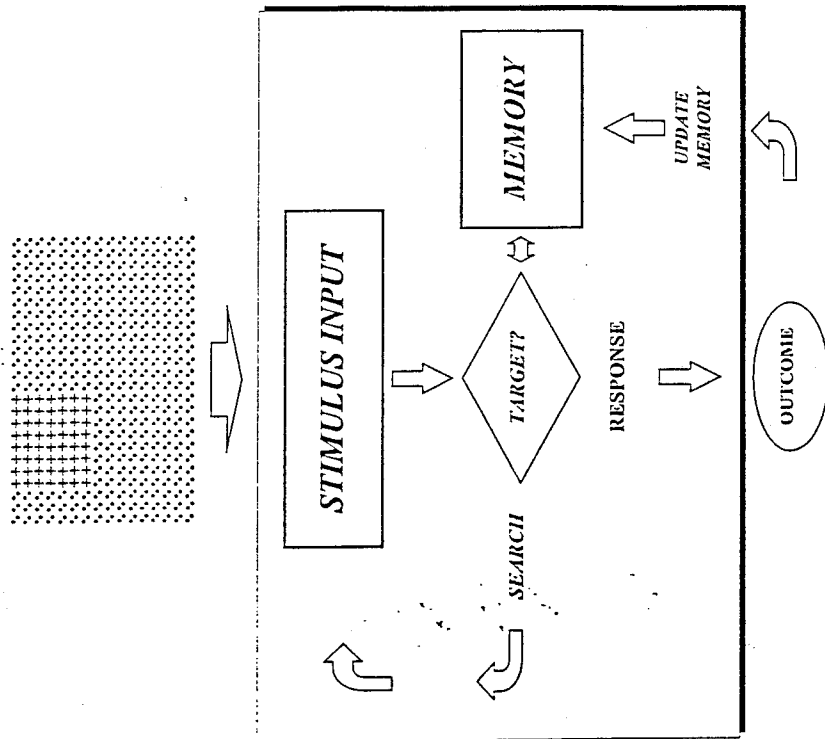


FIGURE 2. The flow of information in birds when performing texture discriminations. The diagram illustrates the interaction among the underlying mechanisms of perception, memory, and search in the target localization task.

current perception of the display matches a bird's encoded "target" definition, then the pigeon should peck at this portion of the display. If it does not match, then a third mechanism is needed to move or guide search to a new area of the stimulus. It is to each of these three broad steps—stimulus input, memory comparison, and search—that we now briefly turn our attention to in the final three sections of this chapter.

STIMULUS PROCESSING MECHANISMS IN TEXTURE DISCRIMINATION

Although the discrimination of complex pictorial stimuli by animals has been of great interest for some time (Fetterman, 1996; Herrnstein, 1984; Herrnstein & Loveland, 1964; Lea, 1984; Thompson, 1995; Wasserman, 1995), the specifics of the perceptual mechanisms underlying the processing of such displays has gone mostly unexplored. It was to begin and understand how and what birds processed from complex multidimensional displays that was one of the motivations for beginning our research on visual texture perception in pigeons.

Our research so far suggests that the single best summary of the pigeon's perception of textured stimuli is that it is highly analogous to our own (Cook, 1992b, 1993b; Cook et al., 1996). Our evidence suggests that in pigeons, like with humans, textured visual signals are first segregated into sets of separate dimensional channels based on color, size, orientation, and probably brightness (Cook, 1992b; Cook et al., 1996). Within each of these dimensional channels, component features in the display are then grouped into larger perceptual units based on their similarity and spatial proximity (Cook, 1992b). In addition to establishing such fields of featural homogeneity, these early mechanisms also establish the relative location of strong featural and regional contrasts in such displays (Cook, 1993b; Cook et al., 1996). We have further established that these grouping and segregation mechanisms operate quite rapidly, providing useful target information within 100 to 200 ms of display onset (Cook, 1992a; Cook, Cavoto et al., 1997). Much like in humans (e.g., Cave & Wolfe, 1990; Hoffman, 1979; Marr, 1982; Poggio, Gamble, & Little, 1988; Watt, 1988), it appears the pigeon's early visual mechanisms are well designed for rapidly detecting and locating featural differences defining object surfaces and their associated edges and contours, mechanisms that would well serve these excellent and acrobatic fliers.

The most revealing evidence concerning the existence of dimensional channels in pigeons comes from experiments with *feature* and *conjunctive* textured stimuli (Cook, 1992b; Cook et al., 1996). In feature texture displays, the elements of the target region contrast with the surrounding distractors along one dimension while both regions contain irrelevant variation within the other dimension. For example, a feature-color display might consist of a target region of randomly mixed blue circles and Ts amidst a background of randomly mixed yellow circles and Ts.

Likewise, a target region of yellow and blue circles within a distractor region of yellow and blue Ts would form a feature-shape display. Conjunctive displays, on the other hand, are arranged so that the target contrasts with the distractors by their particular combination of dimensional values. For example, such a display might consist of a target region of randomly mixed blue circles and yellow Ts amidst a background of randomly mixed blue Ts and yellow circles. As a result, feature displays can be discriminated based on information from a single dimension, while conjunctive displays require the integration of multidimensional information. The middle left and right panels of Figure 1 respectively illustrate an example of a feature-color and shape display and the bottom left panel a conjunctive display.

Treisman and Gelade (1980) were among the first to utilize such feature and conjunctive stimulus relations to study human texture perception. They found that feature textures were far easier to segregate than conjunctive ones. From these and additional visual search results, they theorized that early vision consists of a number of separate dimensional channels, in which the mechanisms of perceptual grouping used to discriminate textures operate. Since grouping occurs within the dimensional channels, the structural organization of the conjunctive displays result in a more difficult visual discrimination. In our earliest experiments, we asked whether pigeons would react similarly to feature and conjunctively organized texture displays. Cook (1992b) for example, used a target localization task to test pigeons and humans with feature and conjunctive texture stimuli similar to those used by Treisman and Gelade (1980), and found that the pigeons' reactions to these stimulus arrangements to be markedly similar to our own, with far more accurate localization of feature targets than conjunctive targets.

Cook and associates (1996) recently extended this result by examining the influence of different kinds of feature and conjunctive organizations involving the dimensions of color, size, and orientation. In addition to displays composed from two dimensions, we included feature and conjunctive displays composed from three dimensions which allowed for the degree of feature overlap, or similarity, between the target and distractor regions to be manipulated. Without going into great detail, these experiments forged four further links in the similarity of how pigeons and humans processed such displays, determining that: (1) target/distractor similarity was critical, (2) irrelevant dimensional variation did not hurt performance, (3) there are trade-offs between response speed and accuracy with the conjunctive displays, and (4) the number of distractors present in the displays differentially influenced the localization of feature and conjunctive targets. These similarities suggest that functionally equivalent mechanisms mediate the perceptual grouping, search, and discrimination of textured stimuli in both species.

Besides looking at the organization of these grouping mechanisms, we have also been examining the speed at which these mechanisms operate. The rapidity of detecting differences in textures is one of the defining characteristics of this process in humans. In an earlier study (Cook, 1992a), we indirectly estimated that pigeons probably derive target location information in as little as 150 ms. A more recent set

of experiments confirmed this more directly (Cook, Cavoto et al., 1997). In these experiments, the birds were presented with a series of randomly generated color textures in each trial. These displays were rapidly presented at rates ranging from 100 ms to 1000 ms per display. Thus, during a trial a pigeon might see red squares on a background of green squares, then these colors would change to blue and yellow, then orange and white, and so on, until the bird pecked five times at the target or distractor region. The target's location remained constant within a dynamically changing display, but was randomized across trials. For the birds to have any chance at localizing the target in such a situation, they would need to process the colored differences within the brief intervals that each separate display was available for viewing. From each of these brief views, the pigeons could then integrate information across successive experiences within a trial and localize the target.

We found that the pigeons were able to perform well above chance with displays that changed at rates as rapid as 100 ms. Perhaps the finding was to be expected, since many of our previous results also suggest that, in something highly akin to the human phenomenon of visual "pop out," pigeons can almost immediately detect the presence of unidimensional contrasts in these displays. Further, because of the brief and ever changing nature of these dynamic displays, it seems highly unlikely that the birds were extracting and identifying specific dimensional values. This suggests that the rule for identifying a target is basically relational in nature, suggesting that the birds recognize the target region based on a highly generalized memory of its global characteristics.

MEMORY-RELATED MECHANISMS IN TEXTURE DISCRIMINATION

The birds must maintain and store information about what defines a suitable "target" in order to respond accurately in these tasks. Debates about the content of these memories and how they control an animal's discrimination behavior have a long history in animal learning. This is an issue that has not been limited to non-human animals either, as many of the same concerns appear in studies of intelligence-related differences in humans as well (Soraci, Carlin, Deckner, & Baumeister, 1990). One long standing consideration has been whether the absolute or relational properties of stimuli are most important in controlling an animal's behavior (Kohler, 1925; Spence, 1936). It is now apparent that both factors play a role depending upon the situation. For instance, the tendency for animals to rote memorize various kinds of stimuli discriminations is well established (Carter & Werner, 1978; Edwards & Honig, 1987; Jitsumori, Wright, & Cook, 1988; Ringo & Doty, 1985; Vaughan & Green, 1984). On the other hand, evidence that stimulus discriminations can be learned by animals through the use of generalized rules that transcend the particulars of the stimuli involved has also been found (e.g., Cook, 1992a; Cook et al., 1995; Cook, Katz, & Cavoto, 1997; Wasserman, 1995; Wasser-

man, Hugart, & Kirkpatrick-Steger, 1995; Wright et al., 1988). For instance, it appears that in our target localization task, as well as other forms of such odd-item search tasks, the birds learn a generalized oddity discrimination which they can use to locate and identify the target in the display (Blough, 1989; Cook, 1992a). Hence, when we test our pigeons with novel texture stimuli composed from colors and shapes they have not previously experienced they always continue to respond at above chance levels of discrimination.

Besides being the odd area of a display, the target region of our texture stimuli have other structural components—such as a rectangular shape, straight edges, 90° corners, and a specific size—that might also be helpful in identifying it as the correct area to peck at. Do the birds learn anything about these featural properties of the target? And if so, which are most critical? To answer these questions we recently conducted experiments looking to identify the role of some of these features. These were done by varying the global organization of the distractors surrounding the target region. Those features critical to localizing the target could thus be isolated by determining which distractor organizations most interfered with accurate performance.

In an earlier series of similar experiments, Cook (1993a) found that grouping distractor elements to form small randomly-oriented lines interfered more with target localization than the same number of distractors randomly distributed around the target. This outcome suggested that some linear component of the target—such as its edges, corners, or overall outline—played a key role in the birds' localization of the target. Our newer experiments discussed below were designed to yield more specific information about the nature of these different linear features and their involvement in target-directed behavior.

Our first experiment asked whether the corners or edges of the target were most critical to the birds' performance. These features had been confounded in the linear displays of our earlier study (Cook, 1993a). We were particularly interested in these features because several previous studies using pigeons had found that straight edges, rather than the vertices or corners, were more important to their successful discrimination of complex pictorial stimuli (Killing, De Marse, & La Claire, 1993; Van Hanne, Wasserman, & Biederman, 1992). These latter findings are interesting because they are the opposite of typical human results, where vertices tend to play a far more important role in object identification than edges (Biederman, 1987).

Three types of distractor organizations were presented to five pigeons highly experienced at localizing odd square target regions. For this test, the birds had to localize a 6 × 6 element target region randomly placed among 70 distractor elements. These 70 distractors were grouped to form either: (1) a new linear condition comprised of 14 sets of horizontal or vertical strings of distractors (each five elements in length), (2) an angular condition composed of 14 sets of five elements that each formed a 90° angle, or (3) a spaced condition where the distractors were evenly spaced across the entire display so that no two distractor elements were spatially contiguous either horizontally or vertically. Finally, so as

to best isolate only the role of the target's global structural properties on performance, the target/distractor differences in color and shape that are typically present in our displays were not present. That is, the same elements were used to form both the target and distractor portions of the display, thus leaving only the target's size and shape to define its location.

The top panel of Figure 3 illustrates the results of 14 sessions testing these distractor organizations as a subset of each day's regular texture discrimination trials. Overall, performance on these test trials was generally very good, suggesting that identification of the target was still easy relative to the features shared with the distractors. Nevertheless, we found that linear arrangements of distractors interfered with target localization significantly more than either the angular or spaced arrangements. There was no significant difference between the latter two conditions. As such, these data suggest the birds' memory of the target region is based more on its straight edges than its vertices.

In the second experiment of this series we examined the potential role of orientation. We thought this could be important given the effects of orientation on human search performance (Cavanagh, Arguin, & Treisman, 1990; Treisman & Gormican, 1988; Wolfe, Friedman-Hill, Stewart, & O'Connell, 1992). In this experiment, the pigeons had to locate a 5 × 5 square target region surrounded by one of five different distractor organizations. Examples of these five types are shown in the bottom panel of Figure 3. One of these was like the spaced condition of the first experiment. The other four were new and differed in either their linear orientation and/or figural organization from the target. One of these figures was an outline of a square, while the second was formed of the same line segments made into a cross. The other two were made from the box and cross-like figures, but rotated 45 degrees, to form a diamond and X. The number of elements in these different distractor conditions did depend on the specific figural organization tested, with 88 elements used for square and diamond conditions, 94 for spaced, and 99 for cross and X displays (i.e., a confound).

The lower panel of Figure 3 shows the results from 10 test sessions with these different distractor organizations. Since figural type had no discernable effect, the results have been grouped according to the orientation of their edges relative to the target. Those distractor arrangements having figures that shared the same general orientation as the target's edges significantly interfered with performance more than essentially similar distractor figures that were rotated to a different orientation. We had expected the box-like figure to create the greatest interference because of its similarity to the target's form. But while this figure numerically produced the most interference, it was not significantly worse than the cross-like figure of the same orientation. This somewhat surprising result suggests that the squareness of the target was not a particularly important feature to the birds. This latter conclusion must be qualified to a certain extent since these distracting squares were both smaller and unfilled in comparison to the target. These additional factors may have

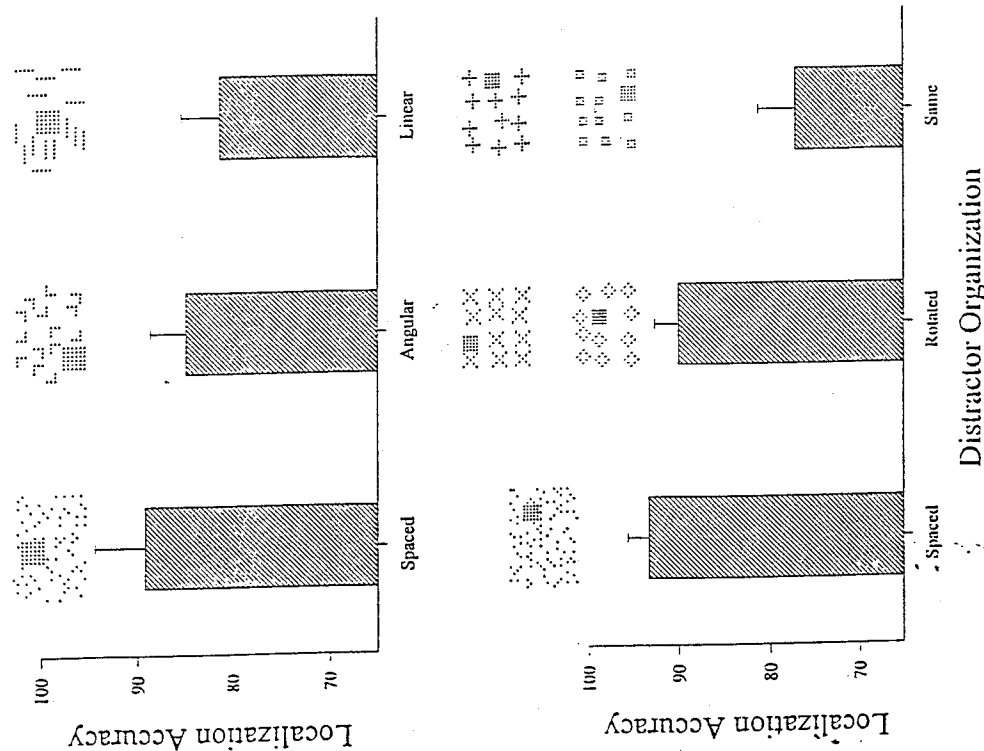


FIGURE 3. The top panel displays mean target localization accuracies from the first distractor organization experiment using spaced, angular, and linear distractor configurations. The bottom panel displays mean target localization accuracies for spaced, rotated, and same orientation display organizations from a second experiment. Representative examples of each of these display organizations appear above their corresponding data point.

masked the actual contribution of the target's shape, by serving as independent cues to the status of the non-target configurations.

These two experiments help to clarify the attributes critical to the successful localization of the target. In general, it appears the vertical and horizontal edges of the target region, rather than its corners and vertices, play the more important role

in localization of the target. This result is consistent with the earlier results of Rilling and associates (1993) and Van Hamme and associates (1992), who also found that line segments were more important than vertices in discriminating pictures of objects. As mentioned, this is different from what is typically found with humans, where vertices are more critical than line segments in rapid object recognition. Other experiments employing visual discriminations have also found results suggesting differences between pigeons and humans (e.g., Allan & Blough, 1989; Cerella, 1977; Hollard & Delius, 1982), but none of these have been broadly examined and strongly confirmed. Our texture stimuli and task are clearly quite different from those used by Rilling and associates (1993) and Van Hamme and associates (1992), yet each study seems to yield the same basic result. If this general pattern holds up to further testing, it portends a potentially important difference in the visual mechanisms of pigeons and humans.

SEARCH-RELATED MECHANISMS IN TEXTURE DISCRIMINATION

The search for food is a key part of any bird's daily existence. While energetic needs dictate what patch of trees to look in or what prey to look for (Stephens & Krebs, 1986), the final phase of this search process is largely controlled by their excellent vision. While discussing all of the intricacies of visual search is not possible in our remaining space, this final section describes new results from our pigeons concerning the interaction of search processes and observing responses on the performance of target-based texture discriminations.

Those behaviors where an animal makes contact with or directs processing towards the discriminative stimulus are often called observing responses. In many situations such observing responses are critical in determining an animal's behavior (Dinsmoor, 1985). For example, increasing the number of observing responses made to the sample stimulus in a matching-to-sample task results in increased levels of discrimination (Brown, Cook, Lamb, & Riley, 1984; Maki, Gillund, Hauge, & Siders, 1977; Sacks, Kamil, & Mack, 1972). Further, animals regularly engage in ancillary behaviors to increase their opportunities to observe or view stimuli which predict reinforcement (e.g., Wyckoff, 1969). Of interest to the present discussion, Jenkins and Sainsbury (1970) found that pigeons learn discriminations faster when the distinguishing feature between two otherwise identical stimuli is associated with reinforcement (the feature-positive condition) rather than non-reinforcement (the feature-negative condition). Interestingly, in feature-positive conditions the pigeons direct their pecks towards the distinctive feature, while they do not in the feature-negative conditions. The different observing responses in these two situations may be critical in the birds' inability to more effectively learn feature-negative discriminations.

Such observing responses probably benefit the animal in a variety of ways. The most obvious is that it ensures that the animal is oriented towards the critical stimulus. More controversially, they may ensure that attentional resources are directed towards the stimulus. Another possible benefit of making contact with the stimulus is that it may allow more efficient or additional coding processes—perhaps involving the response itself (Blough, 1959; Urciuoli & Honig, 1980)—to come into play. Another additional benefit, especially in any visual search task, is that pecks directed at the target may index whether it has been localized or not. Localization, as opposed to mere orientation, may be critical to processing and integrating features of the display. In the human visual search literature, for instance, there has been considerable debate about the necessity and role of spatial localization to target detection and identification (Green, 1991; Sagi & Julesz, 1985; Treisman & Gelade, 1980).

Given these possibilities, we wanted to learn more about the role of the pigeons' observing responses in our experiments. Because locating and pecking the target is the goal of our localization procedure, however, it not particularly well suited for examining such questions. Instead, a task where the option to peck the target and display is available, but not needed to obtain food reward is required. In the last several years, we have developed a choice procedure for studying texture discriminations that has these exact features (Cook et al., 1995).

Two sets of choice experiments will be discussed below. In the first, the pigeons were required to discriminate whether a target was present or not in a textured display, a form of "same-different" discrimination (Cook et al., 1995). In a second, pigeons were required to perform a dimensional identification task where they were not only required to detect whether a target was present or not, but also if it differed from the distractors in either its color or shape. Both experiments employed basically the same choice procedure, with choice responses being made to spatially separated food hoppers located on different sides of the operant chamber. Each hopper was associated with a different stimulus type. Following each texture presentation, these choice hoppers would be illuminated, but not raised. A bird then indicated its choice by putting its head into one of the hoppers. Infrared diodes mounted at the hopper openings sensed a pigeon's approach. If the correct hopper was selected, it would be raised, allowing access to its food contents. Alternatively, if the choice was incorrect, the overhead houselight was turned off for a brief time.

The first set of experiments tested six pigeons previously trained to discriminate between same and different texture stimuli (Cook et al., 1995). The different texture stimuli contained a randomly located block of target elements differing in color or shape from the surrounding distractors (top two panels of Figure 1). The same or uniform textures contained no target and simply consisted of an array of identical elements (see bottom right panel of Figure 1). The pigeons' task was to select the "same" choice hopper following same displays and the "different" choice hopper following any different displays.

In order to examine the role of observing responses to the texture displays in this task, we selected 90 training sessions for each bird that were collected after they had considerable experience in the task (>800 sessions). During these sessions, the birds experienced a mixture of two types of trials. One type (FR trials) required either one or two pecks, depending upon the bird, *anywhere* on the texture stimulus. The second type (duration trials) had no peck requirement, with the stimuli appearing for fixed durations of either 100 ms, 500 ms, 1000 ms, or 2000 ms. For the 78 "different" stimulus trials that were tested each session (involving equal numbers of color, shape, and redundant [color & shape] displays), each trial was then classified according to whether the bird had: (1) pecked only the distractor region during the display's presentation, (2) pecked the target region once, (3) pecked the target region more than once, or (4) never pecked the display at all (these involved duration trials only). The 78 "same" stimulus trials presented each session were classified only in terms of whether the display had been pecked or not. Would the pigeons' choice behavior be equally effective following each of these different types of observing responses?

Overall, we found that for both same and different trials choice accuracy was higher when the birds pecked the display than when they did not. Looking in more detail at the different trials, we found the birds were better when they had pecked at the target than not. Further, the more pecks directed at the target, the better the birds generally performed. Interestingly, we also found that on those different trials where the birds had pecked only at the distractor region, their level of performance was no higher than when they had made no pecks to the display.

Because this is a correlational analysis determined by the pigeons' self selected behavior, several additional factors need to be considered before any strong conclusions about the role of pecking behavior per se can be made. For instance, not all of the different displays were equally discriminable to the birds. If, for example the pigeons only peck the targets of highly discriminable displays, their higher accuracy may only reflect this selection rather than any separate contribution from the act of making the observing response. In order to examine how the discriminability of the displays may have interacted with the form of the observing responses made by the pigeons, the mean level of choice performance supported by each of the different possible combinations of the 10 colors and 10 shapes used in the experiment was determined. Each of these color and shape combinations was then assigned to one of four levels of discriminability according to its mean hit rate across birds: 20 to 40 percent different responses (Poor), 40 to 60 percent (Moderate), 60 to 80 percent (Good), 80 to 100 percent (Excellent). The results of this analysis are shown in Figure 4, which displays the pigeons' choice performance as a function of the type of observing response and the discriminability of the display (color and shape trials only). What this figure clearly shows is that the influence of pecking the display remained the same across all levels of discriminability.

We were similarly concerned that the correlation between pecking behavior and choice accuracy might also be mediated by the target's position in the display. In

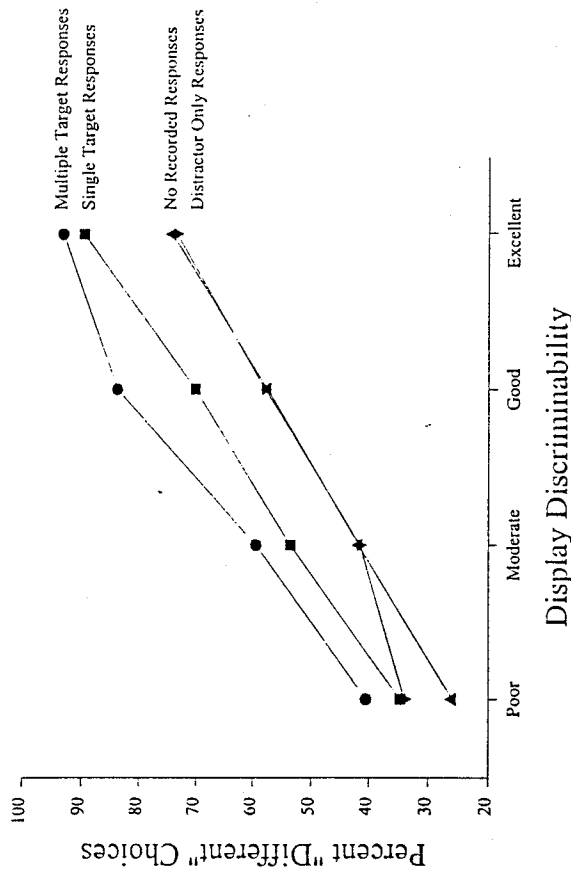
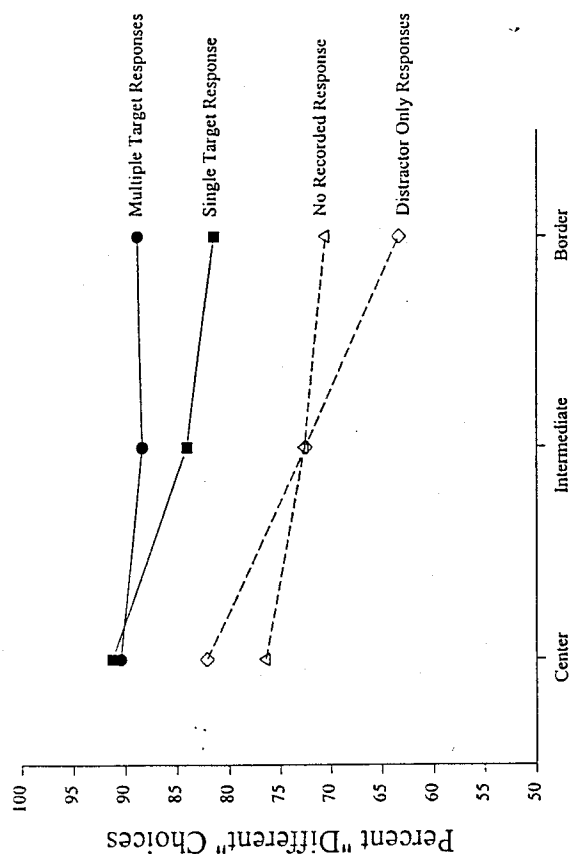


FIGURE 4. Mean percent "different" choices recorded on color and shape trials (combined) as a function of the type of pecking behavior and display discriminability (see text for details).

other settings, we have found that targets in the center of the display support better performance than those located in the periphery. As such, if these birds showed any predisposition to peck the center of the display, then the increased accuracy found on target-directed trials may only reflect this form of response bias. The data in Figure 5 shows this is also not the case either. This figure shows performance as a function of pecking behavior and target position (this analysis was limited only to color and shape displays of Good to Excellent discriminability). Again, the benefits of directing pecks at the target region are clearly seen even when target position is taken into account. While the birds perform better when the target is located in the center of the displays, it is notable that the benefits of pecking at the target actually increase as it moves away from the center of the display relative to the distractor only and no response conditions (i.e., compare the slopes of the filled symbols to the unfilled symbols in Figure 5). Thus, it appears that observing responses, especially those that are directed at the target, facilitate subsequent choice performance independently of either the target's position or its discriminability.

It is important to point out that while these highly experienced pigeons were not required to peck at the target during the selected sessions, nor were they doing so with any great regularity (only about 50% of the total trials), their early training in this discrimination had involved a target-directed response requirement (Cook et al., 1995). During this time the birds were required to peck the target region of



Target Spatial Position

FIGURE 5. Mean percent "different" choices recorded on moderate to high discriminability color and shape trials (combined) as a function of the type of pecking behavior and the target's spatial position in the displays.

different displays five times prior to making a choice response (to equate for number of responses, pecks to same trials were yoked to an individual bird's pecking behavior on different trials). Although we later eliminated this contingency, and it had not been in effect for some time before these data were collected, the overall superiority of choice behavior following target-directed observing responses may still represent a residual effect of that prior experience. Because of this concern, we next examined data from a second set of experiments involving birds who had never received any explicit training to peck the target region of the displays at any point in their experimental history.

The task of the four birds tested in this second experiment was to categorize texture displays based on whether there was a difference or not, and if so, whether it was a color or shape difference. Thus, following the presentation of each display, three choice hoppers were simultaneously illuminated—one each for uniform, color, and shape displays. The results from this procedure are of interest to the current discussion for two reasons. First, as mentioned, at no point in their training was any particular form of the pecking response required of these birds, allowing the contributions of spontaneously generated observing behaviors to be examined. Second, the addition of a third response alternative provided the opportunity to

examine in more detail the effects of different observing responses on the pattern of choice errors made by the birds.

The 150 daily training sessions selected for this analysis consisted of 120 trials composed of equal numbers of color, shape, and uniform trials. Each display consisted of a 16×16 array of elements. On uniform trials, all of the elements of the display were identical in their color and shape. On color trials, 64 of the elements differed in color from the other elements. On shape trials, 64 of the elements differed in shape from the other elements. These 64 "target" elements in the color and shape displays could be arranged in one of two ways. In *aggregate* displays, the target elements were arranged into a randomly located 8×8 square region within the surrounding distractors. In *distributed* displays, the 64 individual target elements were randomly distributed and intermixed among the surrounding distractor elements. For brevity, we plan to limit our discussion to performance with aggregate displays. Displays were presented to the birds using a VR response requirement, which required the birds to make 1 to 12 pecks per trial to gain access to the choice hoppers.

All VR trials of 4 pecks or greater were then categorized into five bins according to the percentage of pecks directed at the aggregated target region of color and shape displays (i.e., 0–20, 21–40, 41–60, 61–80, 81–100%). Despite never being trained to peck the target, these birds similarly showed enhanced choice performance on trials where a majority of observing responses were directed at the target region. More interesting, however, is the pattern of choice errors made by the birds as a function of this target-directed behavior. Figure 6 shows the percentage and type of incorrect choices made on color and shape trials. Two results are of note. First, the percentage of incorrect dimensional responses (reporting "color" on shape trials; reporting "shape" on color trials) was constant regardless of the number of pecks directed at the target. Second, the percentage of incorrect uniform responses systematically decreased as the proportion of target-directed responses increased. These two results suggest that errors in this task were derived from two sources. The first, best indicated by incorrect dimensional choices, represent responses where the birds were not under any form of stimulus control (e.g., inattention to the display itself; see also Blough, 1996). The second, best indicated by the pattern of incorrect uniform choices, represent misses or "target search failures," where the birds were under stimulus control, but inappropriately reported back the uniform area they had scanned over to that point.

Collectively, these two sets of experiments revealed similar effects with regard to the role of observing responses. In each case, pecks directed to all types of displays tended to improve choice accuracy, in agreement with similar previous research (Brown et al., 1984; Maki et al., 1977; Sacks et al., 1972). This is not the entire story, however. The present studies also strongly indicate that where the birds peck is a decisive factor, too. When pecking behavior is directed at the crucial target, the birds are consistently more accurate in reporting a difference than when a comparable number of pecks are directed at the distractor region! While pecking

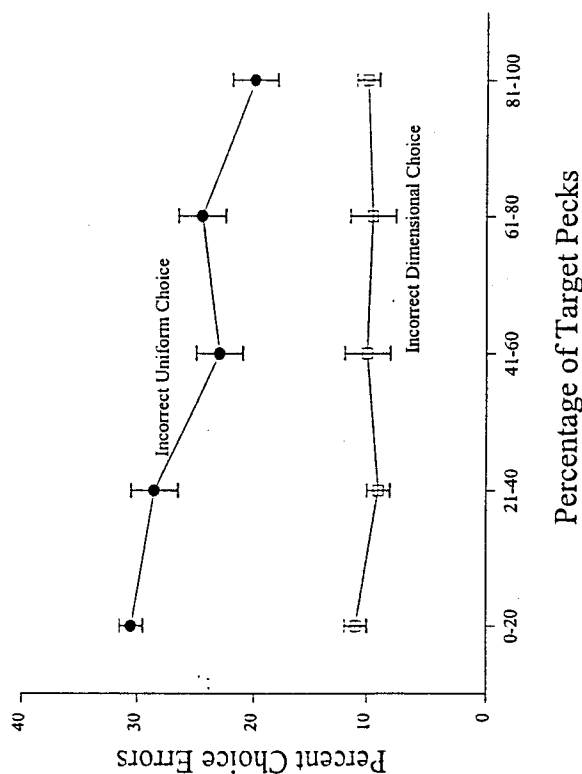


FIGURE 6. Mean percentage of choice errors on color and shape trials as a function of the percentage of pecks directed toward the target area (aggregate condition only). *Incorrect dimensional choices* (unfilled squares) represent those incorrect responses on color and shape trials to the orthogonal dimension's choice alternative (i.e., selecting the color hopper on shape trials and the shape hopper on color trials). *Incorrect uniform choices* (filled circles) represent those incorrect responses to the uniform hopper on color and shape trials. The percentage of correct choices is *not* shown, but can be determined by subtracting the sum of the incorrect choices from 100 percent.

the target is not absolutely critical to discrimination, the present analyses make it abundantly clear that such observing responses do help the pigeons. These data, especially the error data from the last experiment, suggest that there is a strong link between where the birds are looking and their pecking behavior. As such, we think the most likely reason that pecking the target is helpful is not because of any generalized facilitation mediated by pecking per se, but that these trials empirically reflect those occasions where the birds had already successfully found the target.

CONCLUDING REMARKS

The modern study of animal cognition examines how animals encode, transform, compute, remember, retrieve, and manipulate symbolic representations of the world's spatial, temporal, and causal textures for the purpose of adaptively organizing their behavior. This new emphasis on how animals process information is hopefully well illustrated by the above overview of our recent research on visual

cognition in the pigeon. Armed with such detailed information about how these remarkable animals search and recognize different types of complex visual information, we hope to lay the groundwork for an enhanced evaluation of the more advanced intelligent behaviors, such as concept utilization and complex problem solving (Cook, Katz, & Cavoto, 1997).

In the future, we hope to interweave the new threads spun from the current studies into the fabric of several other areas. In particular, we are interested in bridging the gap between the behavioral model outlined above and establish its links and specific relation to the various neural mechanisms in the avian brain (Katz, Cook, Cavoto, & Shimizu, 1997). In addition, we also want to begin to provide more detailed and precise computational and mathematical models and descriptions of the different processes that we have isolated (Cook & Wixted, 1997). With these new links, we hope to eventually generate a more complete and integrated behavioral, computational, and neural description of avian visual cognition. From such a description, along with ones provided for other animals, it should be possible to better understand the mechanisms of intelligent behavior in both human and non-human animals.

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