

One of the most interesting and difficult of scientific questions is how other kinds of animals think about the world we share. One long-standing approach to this question has focused on measuring and comparing the cognitive capacities of different animals (Darwin 1872; Morgan 1894; Romanes 1883; Thorndike 1911).

Birds play an important role in such comparative cognitive studies because they offer a unique, nonmammalian perspective on our understanding of these issues. Like mammals, over the past 200 million years these endothermic animals have evolved separately to interface with the events and objects of the world by employing a highly dynamic and interactive mode of living. This has placed similar demands on the sensory and cognitive processes of both of these classes of vertebrates. For instance, it is no accident that these two groups are the most visually sophisticated animals on the planet. Unlike mammals, however, the demands of flight have required birds to keep their body weight to a minimum, limiting them to small but apparently powerful central nervous systems for processing information.

One of the objectives of my research is to understand this paradox of how birds meet the perceptual and cognitive demands of their interactive mode of living with such small and limited neural equipment. My research is directed at understanding visual cognition in one kind of bird, the pigeon (*Columba livia*). During the past 50 years, pigeons have become an important species in the comparative study of perception and learning. This is because a great deal has been established about their basic behavioral processes and nervous system (Zeigler and Bischof 1993), and powerful and precise laboratory methods have been developed for experimentally investigating these processes.

Possessing a sophisticated visual system with established capabilities for color vision, form

perception, and pattern recognition, pigeons are capable of learning a wide variety of simple and complex visual discriminations (Cook 2000). This can be seen in our research over the past few years, which has explored perceptual segregation and the mechanisms of visual search (e.g., Cook 1992a, b), the discrimination and perception of objects and the contribution of motion to these processes (Cook and Katz 1999; Cook et al. in press), and the learning and use of abstract concepts (Cook et al. 1995, 1997a, 1999; Cook and Wixted 1997). Because of its direct implications for the overarching themes developed in this volume, the remainder of this essay focuses only on the latter line of research.

The Comparative Psychology of Same-Different Concept Learning

Human behavior is often rule based. We can easily answer questions about things with which we have no direct experience, often using simplifying rules or general principles abstracted from the relations among a set of elements. The benefits of this cognitive ability are that it releases behavior from the direct control of the stimulus and its history of reinforcement, allows us to engage in behaviors unbounded by our experience with specific stimuli, and permits highly flexible and adaptive solutions to novel problems. Such relational rule-based concepts allow us to make accurate inductions about new events and their relations; they also form the basis for our use and appreciation of language, mathematics, analogical reasoning, social relations, and even fine arts such as music. As a species, we are expert at detecting and abstracting the general patterns present in the world's particulars.

While many animals often respond to specific stimulus situations with a fixed or limited repertoire of innate or learned behaviors, it has also

become clear that some animals can detect and abstract the patterns present in the world. An understanding of the distribution, mechanisms, and conditions of this conceptual behavior in animals is essential to unraveling its evolution and function. The most widely known example of animal conceptual behavior has involved the categorization of objects, such as chairs, cars, flowers, fish, birds, mammals, trees and so on, from sets of pictures (Bhatt et al. 1988; Cook et al. 1990; Herrnstein and Loveland 1964; Herrnstein and De Villiers 1980). Far less well studied has been whether animals can form abstract rules regarding the relation of one event or stimulus to another. Research of the latter type has focused on investigations of such topics as serial pattern learning (e.g., Fountain and Rowan 1995), transitive inference (e.g., von Fersen et al. 1991), the development and use of syntactic rules (e.g., Kako 1999), and the learning and formation of relational concepts such as same-different (S-D) (e.g., Cook et al. 1997a) and identity (e.g., Wright et al. 1988).

Because of this gap, my recent work has focused on how pigeons perceive and potentially conceptualize same-different relations among visual elements. The detection and recognition of difference and identity are among the oldest and most fundamental of psychological discriminations. They are central to many types of advanced intellectual functions and behaviors, and have important roles in the processes of perception, discrimination, choice, sequential behavior, intelligence-related behavior, and its symbolic mediation by language. James even suggested that the recognition and integration of the "sense of sameness is the very keel and backbone of consciousness" (James 1910, p. 240).

The S-D task is one of the most powerful means of studying the discrimination of such stimulus relations. In this task, the subject is asked to respond "same" when two or more stimuli are identical and "different" if one or more of the stimuli is different from the others. After learning this discrimination, the degree to which this behavior transfers to novel situations

is taken as evidence of concept formation. Early attempts to use S-D procedures with pigeons met with limited success (Edwards et al. 1983; Fetterman 1991; Santiago and Wright 1984). Such results led some to suggest that this relational concept might be beyond the intellectual faculties of this particular animal (Pearce 1991; Mackintosh et al. 1985; Premack 1978, 1983; Wright et al. 1983).

In contrast, we have recently met with more robust success in producing S-D discrimination and concept formation in pigeons across a wide variety of stimuli and procedures. This variety may be in part responsible for our success, but it is also essential to building a convincing argument for any conceptual explanation of this behavior. This is because five operational criteria should be met in order to argue that an animal has formed a conceptual representation. These include (1) evidence of the successful discrimination of the targeted categories or rule during training, (2) evidence of discrimination transfer to novel exemplars of the target concept as recorded on the first trial or prior to any differential reinforcement, (3) evidence that the individual items within the stimulus classes used during training can be discriminated from each other, (4) evidence that the transfer items can be discriminated from the training items, and finally (5) evidence ruling out stimulus control by alternative features that are irrelevant to the concept under study.

Criteria 2 and 5 are typically judged the most important, with 3 and 4 generally overlooked in most studies. In the work described here, the evidence of transfer to novel stimuli is rather plentiful (criterion 2), but because of the perceptual origins of the concepts of same and different, ruling out alternative accounts of the features controlling this transfer (criterion 5; Mackintosh 2000) has turned out to be the more critical part of our studies.

The next two sections describe complementary approaches to obtaining evidence of conceptual behavior in animals. They illustrate empirical strategies that use behavioral techniques to in-

investigate mental notions such as concepts and rules. The first section describes some of our published data on simultaneous S-D conceptual behavior, while the second reports some new data looking at successive S-D behaviors. In both, testing is done with computer-driven, touch-screen-equipped operant chambers in which the stimuli are presented on computer monitors, allowing both maximum control and flexibility in our stimulus presentations.

Simultaneous S-D Discrimination and Transfer

Color and shape-textured S-D displays, like those depicted in the top row of figure 29.1, were the first stimuli with which we established that pigeons could discriminate very large numbers of S-D displays and readily transfer this behavior to novel displays (Cook et al. 1995; see also Wasserman et al. 1995). A typical S-D trial in this procedure starts with a peck at a white "ready" signal, which is then followed by the presentation of a same (all elements identical) or different (containing a randomly located block of contrasting color or shape elements) display in which all the elements are simultaneously present on the display. The pigeons then indicate their reaction to the display by choosing between two "choice" hoppers located on opposite sides of the chamber (e.g., left, different; right, same). A correct choice is then reinforced with food. Based on a variety of evidence at that time, we argued that the pigeons might have used an abstract concept to solve this textured S-D discrimination (Cook et al. 1995). A quick examination of these texture displays revealed, however, that several alternative sources of control still demanded investigation. For example, the simple presence or absence of a perceptually contrasting square "box" could have been the source of control, and not a more cognitive concept of sameness and difference.

To specifically examine such perceptual alternatives, we (Cook et al. 1997a) conducted an experiment testing pigeons with four types or classes of highly variable S-D stimulus displays, examples of which are shown in figure 29.1. The

top row shows the texture display type tested in the first study (Cook et al. 1995) and also used in this second study. The second row shows the feature display type, which because of its design involving randomized local elements required the animal to detect the global S-D relations of the display (Cook 1992b). The third row shows the geometric display type, which defined display difference with only a single odd element. The last row shows the object display type, consisting of digitized natural objects (e.g., flowers and birds; the details and rationale for these four display types are contained in Cook et al. 1997a). Taken together, these different classes created an extreme variety and number of ill-defined, polymorphic, global, S-D displays that break any direct correlation between simple perceptual features and the conceptual status of the displays.

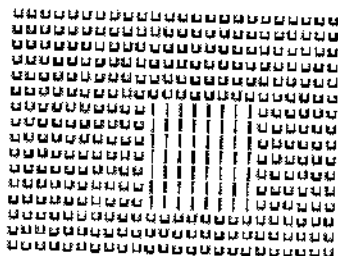
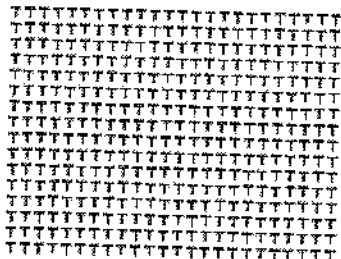
We found that pigeons could still easily learn an S-D classification of these multidimensional classes. Furthermore, learning proceeded at the same rate for all four types, suggesting that only a common discrimination rule was being applied to each distinct type. We also found that these birds transferred their discrimination behavior to novel examples of each class (see figure 29.2).

In subsequent experiments (Cook et al. 1999), we were further able to establish that the majority of these pigeons could transfer this S-D discrimination behavior to a fifth novel stimulus class (color and gray-scale photographs) they had never seen before. This latter transfer is particularly important in showing the relative degree of abstractness of their discrimination. The more abstract a conceptual representation, the greater the range of novel conditions to which it should apply. Our results are among the first, to our knowledge, that establish transfer to stimuli far outside of the range of values experienced during training. As such, the pattern of results from these three studies is consistent with the idea that pigeons can detect, recognize, and abstract simultaneously presented S-D relations. While appeals to simple features seem no longer tenable, a skeptic could, nevertheless, still argue

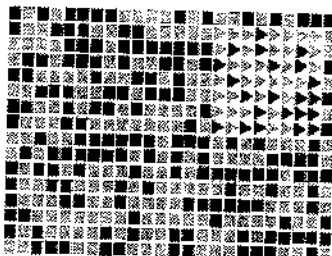
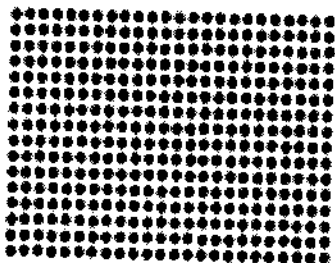
SAME

DIFFERENT

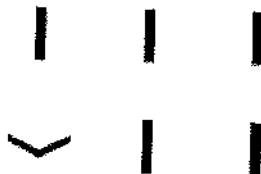
TEXTURE



FEATURE



GEOMETRIC



OBJECT



that perhaps they only learned to detect the generalized presence or absence of large-scale spatial discontinuities among the repeated elements of these displays and did not acquire a true concept.

Successive S-D Discrimination and Transfer

To begin dealing with such possibilities, we have recently developed a new S-D procedure that eliminates such spatial discontinuities. Using a go-no-go discrimination, new pigeons were shown an alternating sequence of either identical (AAAA ... or BBBB ...) or different (e.g., ABAB ...) photographic stimuli over time (see figure 29.3). Pecks to same sequences (S+) were reinforced on a VI-10 variable interval schedule, while pecks to different sequences (S-) eventually produced a brief time-out following their presentation. During each 20-second trial, photographs were successively presented for 2 seconds each, with a 0.5-second blank interstimulus interval separating each one. We have now successfully trained four pigeons to discriminate the successive pairwise S-D arrangement of 60 photographic stimuli. Most important, evidence of concept formation was confirmed by finding significant transfer to novel photographs.

These data can be seen in figure 29.4, which shows peck rates to baseline same and different trials for both nonreinforced probe training stimuli and novel transfer stimuli. Although discrimination behavior was reduced with the novel stimuli, the peck rates for the same sequences were significantly higher than for the different sequences for all birds. These data show that

pigeons can learn a two-item S-D discrimination and form a concept, even when these relations are presented successively over time. These results help to argue against concerns that our previous S-D results may have been due only to detecting generalized spatial or perceptual patterns within the displays.

Conclusion

Our results suggest that pigeons may have a previously unappreciated capacity for learning and using abstract S-D relations among individual elements across a wide variety of stimuli (texture, feature, geometric, object, photographs) and that they can do so whether these relations are presented simultaneously or successively. Returning to our criterion for concept formation outlined earlier, our pigeons easily learn these types of discrimination (criterion 1), even with markedly different stimuli (criterion 3). Most important, they readily show transfer of discrimination to novel items (criterion 2). This transfer is typically reduced in comparison with that for the familiar training items, indicating that the birds recognize and discriminate between the training and transfer items (criterion 4). Furthermore, multiple tests for simpler alternative accounts have not been successful (criterion 5).

Taken together, these different lines of evidence support the hypothesis that our birds are learning a single discriminative rule that is broadly applied to both familiar and novel stim-

Figure 29.1

Representative examples of the original four display types used by Cook et al. (1997a) in training the pigeons tested in these experiments. The left column shows examples of same displays for each display type (the example for the feature display type depicts a shape-same display). The right column shows examples of different displays differing in shape for each display type. For the texture, feature, and geometric display types, there were also corresponding displays in which the elements differed in color. Multiple different colors and shapes and pictures were used to create the large number of displays. The different colors are represented by different levels of grey scale. (Adapted from the *Journal of Experimental Psychology: Animal Behavior Processes* 23: 417-433. Copyright 1997 by the American Psychological Association.)

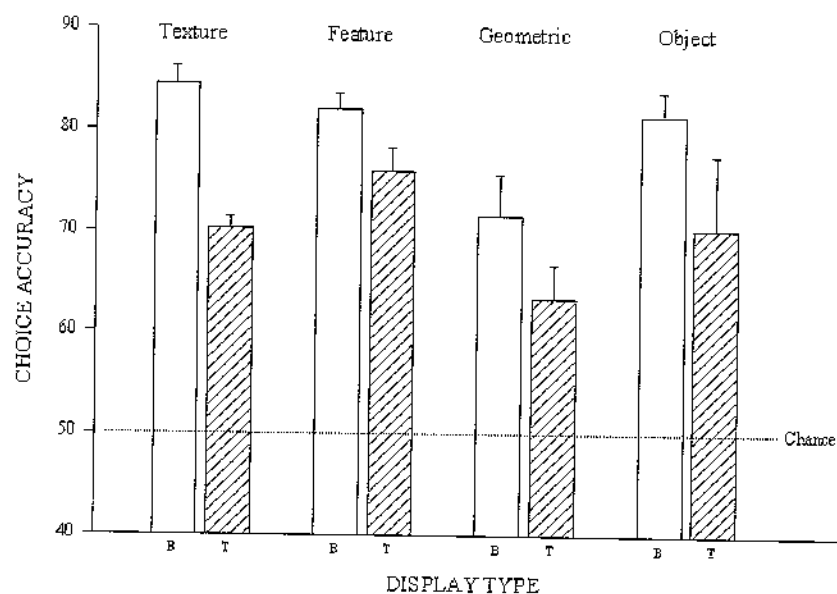


Figure 29.2

Mean choice accuracy on baseline (B) and nonreinforced novel transfer (T) trials for each of the four display types in Cook et al. (1997a). The dotted reference line represents chance performance in the task. (From the *Journal of Experimental Psychology: Animal Behavior Processes* 23: 417-433. Copyright 1997 by the American Psychological Association.)

uli from within and outside the range of their past training experiences. Our newer results indicate that this decision can be reached with as few as two stimuli. Such evidence strengthens the claim that pigeons may be capable of formulating rule-based concepts that give them previously undocumented behavioral flexibility in regard to identity and difference judgments, much like higher primates. Thus this integral component of intelligent behavior may be more widespread in the animal kingdom than previously supposed. Furthermore, it challenges prior claims that S-D behavior (Premack 1978, 1983), and rule-based behavior more generally (Ashby et al. 1998), are critically tied to language.

Looking to the future, our results create something of a paradox that needs further exploration. Despite our results, there is good evidence

that pigeons are often extremely stimulus specific and capable of memorizing large numbers of exemplars and their relations (Carter and Werner 1978; Edwards and Honig 1987; Vaughn and Green 1984). This type of stimulus-specific learning restricts transfer to novel situations, which is exactly the opposite of what we have found. Thus there is evidence that both exemplar and conceptual-driven behaviors seem to coexist in the pigeon.

How then are these two distinct forms of learning to be reconciled? Do they reflect different aspects of the same process or separate and distinct processes, as proposed for humans (Ashby et al. 1998)? One popular solution in the human categorization literature is that they reflect the same exemplar learning process. The notion here is that categorizing behavior is

derived from judging the similarity of any new stimulus to a set of stored exemplars. Several exemplar-based theories of pigeon discrimination learning have been proposed (Astley and Wasserman 1992; Chasc and Heinemann 2001; Pearce 1991), and it will be interesting to see how they fare in accounting for concept results like those briefly described here. Future work clearly needs to focus on a resolution of such issues. Another important issue for us to address is the degree of transfer between simultaneous and successive procedures. If the pigeons are truly abstracting general S-D relations, it should not matter which procedure is used for training and which is used for testing; the behavior should be readily transferred back and forth.

Nevertheless, in conjunction with research investigating insects, amphibians, mammals, and computers, the promise of the current comparative approach is that we can differentiate those general information-processing principles and mechanisms that are shared by many species from those that are unique or specific to individual species or groups, and determine their functions and the conditions for their development. Such information is critical to understanding the evolution of cognition in both human and nonhuman animals. For the moment, however, our goals are far more limited as we continue to try and understand the challenge of just how one small, complex, autonomous biological system, the pigeon, acquires information about object and event relations in the world and the basis by which it flexibly extrapolates this knowledge to new situations.

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