RELATIONAL AND ABSOLUTE STIMULUS LEARNING BY MONKEYS IN A MEMORY TASK

ANTHONY A. WRIGHT, ROBERT G. COOK, AND
DONALD F. KENDRICK

UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON
GRADUATE SCHOOL OF BIOMEDICAL SCIENCES

Three experiments showed stimulus control by either the absolute properties of probe stimuli, relational properties of the probe-list relationship, or both in a serial probe recognition memory task in which a four-item memory list was followed by a single probe (test) item. In Experiment 1, 3 rhesus monkeys received 39 to 75 repetitions of the same 24-trial stimulus sequence. Special tests showed stimulus control by the absolute properties of the probe stimuli. Retention of previous relational control was demonstrated by the good transfer (83%) to novel list and probe stimuli at the beginning of Experiment 2. During Experiment 2, control by absolute properties of the probe stimuli gradually reoccurred. Only a small measure of control by list stimuli could be detected or promoted. In Experiment 3, 4 monkeys were shown to have largely lost their ability to perform on the basis of the list-probe relationship, and were performing primarily on the basis of the absolute properties of the probe stimuli. Over the next 15 weeks, these monkeys were transferred to new stimuli at the beginning of each week. Control by the relational aspects of the task gradually returned. As transfer performance increased, control by the absolute properties of the probe stimuli was eliminated. The results are discussed in terms of stimulus control and performance strategies used by the monkeys.

Key words: memory, stimulus control, absolute stimulus control, relational stimulus control, strategies, relational learning, picture stimuli, monkeys

A recurrent issue in animal discrimination learning has been control of behavior by the absolute properties of individual stimuli or control by the relational properties between stimuli (Gonzalez, Gentry, & Bitterman, 1954; Hanson, 1959; Hearst, 1968; Honig & Urcioli, 1981; Hull, 1943; Kendler, 1950; Köhler, 1918; 1925; Lashley, 1942; Lawrence & DeRivera, 1954; Premack, 1978, 1983a, 1983b; Riley, 1968; Rilling, 1977; Spence, 1936, 1937; Staddon, 1983; Wright, in press; Wright, Cook, Rivera, Sands, & Delius, 1988; Zeiler, 1963; Zentall & Hogan, 1974). Köhler (1918/1939) proposed that animals were capable of learning relations between stimuli. He trained chickens on a brightness comparison and gave them transposition tests to other brightness comparisons; the results supported the proposition that the brightness relation controlled performance. Counterproposals followed in which these transposition results were ac-

counted for in terms of absolute control through associative mechanisms of excitation and inhibition (Spence, 1936, 1937). Evidence accumulated in support of excitation and inhibition associations to the absolute properties of individual stimuli (e.g., Hanson, 1959; Hearst, Besley, & Farthing, 1970; Honig, Borneau, Burstein, & Pennypacker, 1963; Reynolds, 1961). Impetus for conceptualizations of learning in terms of absolute stimulus properties came from its apparent greater parsimony (Honig & Urcioli, 1981; Moyer & Thomas, 1982; Weiss & Schindler, 1981), which in some cases may be more apparent than real (Zeiler, 1963).

The recent emergence of "animal cognition" as a discipline has spawned renewed interest in relational tasks, especially those of a conditional nature. The matching-to-sample, oddity-from-sample, and same/different tasks, for example, all rely on the relation of two or more spatially or temporally distinct stimuli to control the correct responding of the animal. This relational aspect makes it possible for subjects to learn a rule or abstract concept that transcends the individual training stimuli. Thus, postdiscrimination transfer tests to novel stimuli can test whether an abstract concept or rule has been learned. There is little doubt today that monkeys can learn abstract concepts

Portions of this research were supported by NIMH Grant MH35202 to the first author. R. G. Cook is now at Tufts University and D. F. Kendrick is at Middle Tennessee State University. We are indebted to Jacqueline J. Rivera, David Floyd, and Ella Friedman for their careful assistance with portions of this research. Correspondence and reprint requests should be sent to Anthony A. Wright, Sensory Sciences Center, Suite 316, 6420 Lamar Fleming Avenue, Texas Medical Center, Houston, Texas 77030.

(Harlow, 1949; Overman & Doty, 1980; Wright, Santiago, & Sands, 1984),¹ and recently even pigeons have been shown to learn an abstract concept (Wright *et al.*, 1988). It is equally clear, however, that under certain conditions monkeys and pigeons fail to learn about the relational properties of these tasks. Instead, their responding becomes controlled by the absolute properties of the training stimuli, resulting in poor task transfer to novel stimuli (Berryman, Cumming, Cohen, & Johnson, 1965; Carter & Werner, 1978; Cumming & Berryman, 1961; Cumming, Berryman, & Cohen, 1965; Farthing & Opuda, 1974; Holmes, 1979; Jackson & Pegram, 1970; Santi, 1978, 1982). This naturally raises the issue of what determines when animals will be controlled by the relational properties of the training stimuli as opposed to their absolute properties. This is the topic of the research presented in this article.

In this article it is shown that learning does not take place exclusively with regard to relational stimulus properties or absolute stimulus properties, but rather the type of control depends on the experimental conditions. The experiments of this article used a serial probe recognition (SPR) task. In the standard SPR task, a list of pictures is presented sequentially to the animal. Following this list, a test item or probe is presented in a different location, and the subject decides (by moving a lever) whether the probe was the same as any one of the list items or different from all of them. Monkeys can, with little difficulty, learn this task based upon the list-probe relationship (Sands & Wright, 1980a, 1980b; Wright, Santiago, & Sands, 1984). However it was discovered, somewhat by chance, that in certain training situations the absolute properties of the probe stimuli controlled performance. This article reports changes in the degree of relational or absolute control in different circumstances. We begin with an experiment in which the change to absolute control was first detected. Two subsequent experiments examined more fully the relation between absolute and relational stimulus control and the conditions that promote transitions between them.

EXPERIMENT 1

Subjects in Experiment 1 were 3 monkeys that had been trained in a same/different task with picture stimuli and had learned a same/different concept (Wright, Santiago, & Sands, 1984). During the 4 years since that training and testing, they received approximately 1,000 daily sessions with a wide variety of stimuli that were changed frequently. Just prior to the experiments reported in the present article, the monkeys had not been tested in any particular experiment for some months, and their performance on the SPR task simply was being maintained. The training sequence was presented unaltered during this time and consisted of 108 different travel-slide pictures arranged into 24 trials with four-item lists per trial. Suspicion arose that the monkeys had memorized the correct responses to individual items of the trials. Procedures were devised to test for this possible memorization and control by the absolute stimulus properties of the task items. This experiment reports the results of these tests, in which it was found that monkeys were controlled by the absolute properties of the probe stimuli.

METHOD

Subjects

The subjects were 3 rhesus monkeys (*Macaca mulatta*), Joe, Linus, and Max. They were approximately 7 years old at the beginning of the experiment. The monkeys' intake of food and liquid was regulated prior to experimental sessions and for a short period immediately following. Tests were conducted 5 days a week. On Friday afternoons and Saturday mornings, the monkeys were given free access to Purina Monkey Chow® and water. On Sundays, food and water were regulated to prepare for testing.

Apparatus

A microcomputer (Cromemco Z-2D®) controlled experimental events. Carousel® slide projectors (Kodak 760H auto focus) projected 35-mm color slide stimuli onto rear projection screens (12 cm high by 18 cm wide) located approximately 61 cm from the monkeys' normal eye position for observing the stimuli. The two screens were separated vertically by 17 cm (center to center). Solenoid-operated shutters controlled stimulus exposure.

¹ See also: Wright, A. A., Shyan, M. R., & Jitsumori, M. (1989). *Auditory same/different concept learning by monkeys*. Manuscript submitted for publication.

The stimulus items were color slide photographs of pictures, scenes, and objects. A collection of over 4,000 slides was available. The items for each trial were always different from the items of every other trial, that is, each stimulus was unique within a daily session. Items were selected to minimize generalization and interference within and between trials.

Monkeys sat in a standard primate chair. The juice spout and pellet dispensers were positioned to allow easy access following a correct response. A three-position T lever (left, right, and down) was located within easy reach of the monkeys.

Procedure

Training. A clicker (5 Hz) signaled the beginning of each trial and lasted until the monkey pressed down on the lever, starting the trial. List items appeared on the upper screen for 1 s each, with a 0.8-s dark period between them. Following the last list item, there was a 1-s delay before presentation of the probe item on the lower screen. The probe item remained in view until the monkey moved the lever to the right or left, or until 10 s elapsed. A "same" response (lever movement to the right) was correct when the probe item matched one of the list items. A "different" response (lever movement to the left) was correct when the probe item matched none of the list items. Correct responses were reinforced with either 5 cc of orange drink (Tang®) or a 1-g banana pellet (Noyes), pseudorandomly determined. Reinforcement was accompanied by a 0.5-s 500-Hz tone. Incorrect responses or failures to make a choice response (aborts) during the 10-s response interval turned on a bright overhead houselight and started a 10-s timeout. A dark 3-s intertrial interval followed response outcomes and separated trials.

A session consisted of 24 trials, with 12 same trials and 12 different trials sequenced pseudorandomly. Each trial contained four list items and a probe item. The monkeys had received 39 to 75 repetitions of the same 24-trial sequence of items (same items in the same order) before the data shown for this experiment were collected. Occasionally, more than one session was conducted daily, and in such cases several hours separated sessions.

Testing. Tests for control by individual list or probe items were made by substituting blank (white) items for the list or probe items (see

also Jitsumori, Wright, & Cook, 1988; Wright, Santiago, Sands, & Urcuioli, 1984). The blank items were constructed of thin white paper mounted in slide frames. They produced a brightness approximately equal (according to the experimenters) to the average of the pictures. The blank items preserved the rhythm of each trial, while eliminating the information of those items they replaced and hence relational information. In the probe-only tests, blank items were substituted for all of the list items in the 24-trial session. In the list-only tests, blank items were substituted for all of the probe items in the 24-trial session. In both tests, the choice responses that were correct during training were maintained as the correct responses and reinforced. Probe-only and list-only tests were conducted in two consecutive sessions following baseline performance of at least 80% correct. One probe-only and one list-only test were conducted each day, with the order of test randomized for each subject.

RESULTS

Figure 1 shows that monkeys performed almost as well on probe-only tests (86.3%) as they did on the immediately prior baseline sessions (94%), and for all 3 subjects in each condition, binomial tests showed that performance was significantly different from chance ($p < .001$). By contrast, performance on list-only tests (56.7%) was not significantly different from chance ($p > .1$ for each subject). A one-way ANOVA found a highly significant effect of type of test, $F(2, 6) = 80.1, p = .0002$. Both probe-only and list-only test performances were worse than baseline performance, $F(1, 6) = 10.7, p < .05$; $F(1, 6) = 254, p < .001$ for probe-only and list-only, respectively.

DISCUSSION

The history of these monkeys prior to Experiment 1 showed that they were controlled by the list-probe relationship in learning the same/different concept (Wright, Santiago, & Sands, 1984) and in showing orderly changes in their serial position functions with changes in the retention interval (Wright, Santiago, Sands, Kendrick, & Cook, 1985; Wright, Santiago, Urcuioli, & Sands, 1984). In Experiment 1, however, they demonstrated a high degree of control by the absolute properties of the probe stimuli, but not the list stimuli, after the same sequence of items had been repeated

39 to 75 times. This control by the absolute characteristics of the probe items was shown to be independent of the sequence of correct left and right responses (Wright, Santiago, Sands, & Urcuioli, 1984).

Two conditions apparently contributed to this change in control. One condition was that the list and probe stimuli were unique on every trial of a session. Another condition was that the sequence of items was repeated, allowing subjects the opportunity to learn correct responses to individual stimuli. Typically, these conditions do not arise in discrimination experiments, either because a few stimuli are frequently repeated and counterbalanced within the session (Bolhuis & van Kampen, 1988; Buchanan, Gill, & Braggio, 1981; Kesner, 1985; Kesner & Novak, 1982; Roberts & Kraemer, 1981), or because many stimuli are shuffled regularly or replaced between sessions (Sands & Wright, 1980a, 1980b; Santiago & Wright, 1984; Wright, Santiago, & Sands, 1984). In the present experiment, however, the trial-unique condition was used to reduce proactive interference within each session, and repetition of the same item sequence was an unintended by-product of maintenance training.

EXPERIMENT 2

Learning the relations between stimuli within a task allows for the generation of a rule or concept that transcends the stimuli used during training and makes transfer to new stimuli possible. Memorizing the absolute properties of stimuli, on the other hand, requires learning the new correct response for each stimulus, making transfer to novel stimuli impossible. The results from Experiment 1 did not reveal whether control by the absolute properties of the individual probe stimuli had replaced previous relational control or whether both types of control were still present simultaneously.

Experiment 2 tested for the presence of relational control through a transfer test to new stimuli and a new sequence of same and different trials. If learning about the absolute properties of probe items had replaced relational control in Experiment 1, then transfer should be near chance performance. On the other hand, if the monkeys were under rela-

Fig. 1. Average performance of 3 rhesus monkeys under three test conditions: baseline training, in which the four list items presented each trial were followed by a probe or test item; probe-only tests, in which blank white items were substituted for the list items; and list-only tests, in which blank white items were substituted for the probe items.

tional control as well as absolute control, then there should be good transfer.

An additional purpose of Experiment 2 was to document the development of control by the absolute stimulus properties of the probe items. Following transfer testing with the new stimulus set, training continued with the same stimulus sequence, and tests for absolute control were made at periodic intervals in order to examine the time course of changes in control.

METHOD

Subjects and Apparatus

Experiment 2 was conducted immediately following Experiment 1 using the same apparatus. The subjects were the same 3 monkeys (Joe, Linus, and Max), with only Linus and Max participating in the final experimental phase involving continued training in the list-only test paradigm.

Procedure

The procedure was identical to that previously described for Experiment 1, except that the items composing the session for this experiment were new and had never been seen before by the monkeys. The sequence of same and different trials was also different from that previously used. Like Experiment 1, the same

stimulus sequence was repeated throughout this experiment. Procedures for probe-only and list-only tests were the same as in Experiment 1 and were conducted periodically during acquisition, typically as a pair of consecutive sessions with their order alternating.

In the final phase of Experiment 2, the list-only test procedure was continued for 100 consecutive sessions in order to determine whether control by the absolute properties of the list items was possible with these monkeys. In this list-only training, blank white items were shown in place of the probe items, and the responses that had been correct in training continued to be reinforced.

RESULTS

The degree of transfer is shown by performance on the first session with the new stimulus set. It is shown in Figure 2 as the first filled circle of the baseline curve for each subject, because this condition also represented the beginning of repeated testing. Transfer averaged 83% correct (91%, 75%, and 84%, for Joe, Linus, and Max, respectively). Apparently, the new stimuli (and sequence) made control by absolute properties of any of the stimuli impossible. Thus, this good transfer demonstrates that the monkeys in Experiment 1 had retained relational control despite the presence of absolute control by the probe items in the previous experiment. This conclusion is supported by the poor performance on the tests for absolute stimulus control at the beginning of Experiment 2. Both list-only and probe-only test performances were at or below the 50% chance level on the first tests following transfer.

With repeated presentations, however, absolute stimulus control by the probe items returned, as shown in Figure 2. Joe was better than 80% correct on the probe-only test after only 23 repetitions of the item sequence. The other 2 monkeys showed a similar trend on the probe-only tests, but over somewhat longer time periods. In contrast, there was little evidence of control by the list items. After 93 sessions, only Max showed any indication of absolute control by the list items.

The results from 100 sessions of training on the list-only test with the purpose of establishing control by the list items are shown in Figure 3. Linus and Max both showed some

Fig. 2. Individual performances of 3 rhesus monkeys upon presentation and repetition of a new 24-trial session with new memory items. The three conditions (baseline, probe-only, and list-only) are defined as in Figure 1.

increasing control by the list items, $t(19) = 3.25$, $p < .01$; $t(19) = 80.0$, $p < .001$ for Linus and Max, respectively, over their last 20 sessions using a single-mean t test. Max showed more learning and performed at about 70% accuracy at the end of the 100 training sessions.

DISCUSSION

Experiment 1 showed that all 3 monkeys came to be controlled by the absolute properties of the probe items following repetition of the same stimulus sequence. Their excellent transfer performance to the new items of Experiment 2 shows, however, that they had retained the use of their previously learned relational rule. This ability to transfer suggests that absolute stimulus learning does not nec-

Fig. 3. Acquisition performances by 2 rhesus monkeys trained for 100 consecutive sessions on the list-only test, in which the list items were presented each trial but blank white items were substituted for the probe items.

essarily displace relational stimulus learning, at least in this context.

In 23 to 80 repetitions of the same stimulus sequence, however, control by the absolute properties of the probe stimuli returned. Why absolute control develops primarily to the probe stimuli is not precisely clear. This difference in control can be best evaluated by comparing Figures 2 and 3. Max's and Linus's probe-only performances were about 90% after 90 training sessions (with list and probe stimuli both present), whereas after the same number of sessions (Figure 3) performances with list items only were 65%. This comparison actually favors the development of list-item control, because subjects had prior experience with the list items (in the initial phase) and explicit training to establish list-item control (in the final phase). Perhaps the simplest reason why the probe item comes to control performance is because it is the closest to the reinforcer in the chain of trial events. This quite reasonable suggestion does not explain, however, why pigeons tested in similar circumstances come to be controlled by the list items, which are further away from the reinforcer (Wright, Santiago, Sands, & Urcuioli, 1984).

EXPERIMENT 3

Experiment 3 was conducted several months after the first two experiments. During that intervening time, the use of relational information had diminished considerably in these monkeys and the exclusive processing of the probe item seemed to have become the pre-

dominant strategy. Experiment 3 documents the redevelopment of stimulus control by the relational properties of the list and probe. The method chosen to reestablish relational control was a series of successive transfers to new list and probe stimuli that would thereby reduce the time span over which any absolute strategy would be effective. Except for these weekly changes of the items, the same basic procedures that had produced and supported absolute responding in the previous experiments were used. A follow-up test with these same monkeys then showed near perfect transfer to novel test stimuli using a conditional version of the SPR procedure.

METHOD

Subjects

Four monkeys (*Macaca mulatta*) were the subjects. Two of them, Linus and Max, had participated in the previous two experiments, and the others, Felix and Oscar, had more experience on the SPR task than Linus and Max. Maintenance and living conditions were identical to those previously described.

Just prior to Experiment 3, these 4 monkeys had experienced over 200 sessions equally divided between two sequences of 104 trials with four list items per trial. In each sequence, the same order of list and probe items was used, but the four items comprising each list were varied somewhat by slightly offsetting the starting position with each revolution of the Carousel® tray containing the list items. Despite this shuffling procedure, the responding of all monkeys came to be controlled by the absolute stimulus properties of the probe items.

Apparatus

The apparatus was similar to that described in the previous experiments, except that the monkeys were tested unrestrained in a standard primate cage (62 by 62 by 92 cm) instead of a primate chair. Two aluminum bars on the front wall of the cage, slightly to the right of center, were spread apart to allow the monkeys easy access to and manipulation of the response lever.

Procedure

Trial-unique training and transfer. The basic testing procedure for each session was nearly

identical to that previously described, except that the interval between list items was slightly longer (1 s instead of 0.8 s), the intertrial interval was slightly longer (4 s instead of 3 s), and the daily session consisted of 80 instead of 24 trials.

Each daily session consisted of four 20-trial blocks. Each block contained 10 same and 10 different trials. The list length for each trial was four items. Trials were ordered pseudorandomly with no more than three same or different trials appearing consecutively. Different sets of 360 training stimuli (320 list and same probe items and 40 different probes) were used each week. The stimuli were selected from the 4,000-item pool, and most of these training stimuli had been seen previously by the monkeys. Each stimulus appeared on only one trial per session. The order of presentation of the four 20-trial blocks was randomized daily, but trials within each block were repeated identically in a fixed sequence. A short interval of 1 to 3 min separated blocks in order to change the slide trays containing the stimuli.

Transfer tests with four new 20-trial blocks were conducted on each Tuesday of the 15 consecutive weeks of the experiment. The monkeys were then trained with the same set of stimuli for the next 4 test days following transfer, except for the special tests for absolute control by list and probe items.

Probe-only and list-only tests were conducted on the third training day (Friday) following transfer during weeks 3 to 15. These tests were conducted on the second and third 20-trial blocks provided that the subject was 70% correct or better on the first 20-trial block; otherwise they were conducted on the third and fourth 20-trial blocks. The order of these tests alternated weekly, and they were identical in all important respects to those of the previous experiments.

Conditional training and transfer. After completion of the weekly transfer tests, the monkeys were trained with a conditional procedure that allowed the same slide trays to be used repeatedly, but that prevented the development of control by the absolute properties of the probe items. Although the organization of the stimulus items for this training was somewhat complex, other less complex versions (see Subjects section above) had not been successful in maintaining relational stimulus control.

This conditional procedure employed 576 of the previously tested items. They were divided into three stimulus sets (A, B, and C). Each set was subdivided further into two different 24-trial sequences of four list items per trial and arranged in a fixed order in 140-slot Kodak slide trays (labeled A, A', B, B', C, C'). In addition, two sets of probe items were constructed for each of the A, B, and C stimulus sets. Using Stimulus Set A as an example, one set of probe items (labeled AP) was composed from half of the items from each list of Sequence A and half of the items from each list of Sequence A'. The other set of probe items (AP') combined the other half of the items from both sequences. The items in these two probe trays were arranged so that the list items of one sequence, A for example, were available as the different probes for the other list sequence (A') and vice versa. By using the four different possible combinations of the two list sets and the two probe sets (e.g., A-AP, A'-AP', A-AP', A'-AP), the subjects could be tested with any of the four list items on same trials or any of four stimuli from the other set on different trials. The order of the same and different trials, the serial positions tested within a list, and the choice of stimuli to be used as different probes were randomized at the beginning of each day by an off-line program.

Each daily training session consisted of three 48-trial blocks. Each 48-trial block had 24 same trials (each serial position tested six times) and 24 different trials. All six list sequences (A, A', B, B', C, C') were tested every 2 days. The monkeys were then trained with this conditional procedure for 50 48-trial blocks. Following this training, the monkeys were tested over 2 days for the presence of absolute stimulus control. This consisted of using one of the 24-trial sets as a list-only and probe-only test in place of the third 48-trial block for a day. This testing was then followed by transfer tests to novel stimuli.

Transfer tests consisted of 72 trials with four list items per trial, and these 72 trials were organized into three 24-trial sequences (i.e., three different slide trays). Twenty-four of these trials contained items that had not been seen during the previous year, and 48 of them contained items that had never been seen before. Each of the three different 24-trial sequences of list items was tested four times over

Fig. 4. Mean percentage correct for 4 rhesus monkeys on four-item lists in SPR task over a 15-week period. Tests were conducted weekly to test for transfer to new items. Towards the end of each week's training, tests were conducted to determine absolute or memorization strategies by presenting only the test items of each trial (probe-item strategy tests) or only the list items (list-item strategy tests).

a 3-day transfer test period with special attention given to the first test with the novel items. Each test day started with a 48-trial warm-up block using one of the list sequences used in training. This was followed by four 24-trial transfer tests. On two of the test days, the list sequence was tested once. On the remaining day it was tested twice, but separated by the tests of the other two list sequences. Each 24-trial test contained 12 same trials (each serial position tested three times) and 12 different trials. Although the list sequences were repeated over sessions, the probe items were always changed for every test. Each list was tested twice as a same trial, with a different list serial position being tested on successive presentations, and twice as a different trial, using probe items that were not part of any of the list sequences used during testing. The probe items on different trials were novel, and the serial position tested on each same trial was different each time the memory for the list was tested. Thus, each of the 288 transfer trials was unique in its combination of particular list and probe stimuli.

RESULTS AND DISCUSSION

The monkeys showed substantial control by the absolute properties of the probe items prior

Fig. 5. Mean percentage correct in SPR task for 4 rhesus monkeys on baseline SPR trials and transfer test trials with either novel (N) stimuli or those unseen in the previous year (UPY). The error bars are standard errors of the means.

to the introduction of weekly item changes. Accuracy on the probe-only test averaged 69.6% correct, and accuracy on baseline tests, in which both list and probe items were present, averaged 77.6%. List-only test performance averaged 64.5%. There were no significant differences between the baseline, probe-only, or list-only values, $t(3) < 2.35$, $p > .10$ for all three comparisons.

Figure 4 shows the progressive change in the nature of stimulus control over the course of the experiment in 3-week blocks. On the first test for determining the degree of absolute control by the probe items, mean performance was 64.5% correct, and was significantly above chance, $t(3) = 11.2$, $p < .05$. Thus, after only four total exposures to each probe item there was already measurable absolute control by the probe stimuli. This demonstrates the degree to which the monkeys had rapidly come to identify and code responses to the individual probe stimuli. One can reasonably extrapolate from this brief training episode and expect even more control by the probe items had training continued.

Over the 15 weeks of the experiment, however, control by the absolute properties of the probe items declined. Corresponding to this decline, control by the relational properties of the list and probe items grew over successive

transfers. Over the entire experiment, accuracy on transfer tests increased a total of 18%, from the first week (63.5%) to the last week (81.8%) of testing, whereas accuracy on probe-only tests dropped 22% from the preexperimental probe-only test (69.6%) to the last week (47.6%). These opposing trends in absolute and relational control are supported by a significant interaction, $F(4, 30) = 2.87, p = .039$, in a two-way ANOVA of test block and test type (probe only vs. transfer).

Figure 5 shows the results for the transfer tests following conditional training in the last phase of Experiment 3. These transfer results were divided according to whether the items were novel (N) or unseen in the previous year (UPY). Comparisons of baseline accuracy (84.1%) to accuracy with unfamiliar and novel stimuli revealed no reliable differences: unfamiliar, $t(3) = 1.48, p > .12$; novel $t(3) = 1.3, p > .14$. Furthermore, no differences were found between baseline accuracy and accuracy on the first presentation of the novel stimuli, 77.2%; $t(3) = 1.0, p > .19$, or unfamiliar stimuli, 78.9%; $t(3) = 0.9, p > .20$.

Thus, weekly changes in the stimuli shifted control of choice responding over to the relational aspects of the list and probe stimuli and reduced absolute stimulus control. The excellent transfer to novel stimuli with the conditional procedure is one of the best examples of relational rule transfer yet reported for monkeys and further supports the idea that the monkeys were again attending to the relational aspects of the list and probe stimuli. Thus, this particular conditional procedure was adequate to maintain and promote good relational control by the list-probe relationship.

GENERAL DISCUSSION

Nonhuman learning, from the reflexology of Descartes to modern times, has often been perceived and conceptualized as an automatic and mechanical form of learning. Little, if any, latitude has been attributed to the nonhuman's control over its own mental events. Watson's behaviorism, the conditioning theories of Hull and Spence, Skinner's operant conditioning, and the sterile, reductionist confines of the laboratory have done little to dispel this view. Human learning, although now decidedly cognitive, has, in the past, been conceptualized much in the same way: "Psychologists have

not always been comfortable, in the middle of this century, with the idea of voluntary control over mental events" (Crowder, 1976, p. 157). In the 1950s, however, the study of human learning diverged from that of nonhuman learning. Among the many events causing this divergence was the finding that human subjects used different strategies during concept learning (e.g., Bruner, Goodnow, & Austin, 1956). It was not possible to explain this concept learning as the result of associations between elements of the concept exemplars and the correct responses. The results demanded a more active, strategic, hypothesis-testing process. Other evidence supported this view, and the issues in human learning today involve processes such as encoding, storing, retrieving, rehearsing, scanning, consolidating, and processing at different levels. Since this cognitive revolution 30 years ago, the study of human learning has diverged considerably from that of nonhuman learning (see Wright & Watkins, 1987). The recent emergence of animal cognition as a discipline within nonhuman learning suggests that a reconvergence may be under way (e.g., Hulse, Fowler, & Honig, 1978; Kendrick, Rilling, & Denny, 1986; Rescorla, 1988; Roitblat, Bever, & Terrace, 1984).

However, this new cognitive emphasis in the analysis of nonhuman information processing raises many questions and issues. Will the cognitive processes that are hypothesized out-strip our abilities to analyze them objectively? Can one justify attributing active cognitive and mental processes to nonhumans, or will a description of environmental and behavioral events (in S-R, S-S, and R-S terms) suffice? Some of these issues can be briefly considered by juxtaposing summaries of the experiments of this article, one in behavioristic terms and the other in cognitive terms.

First, the description in behavioristic or stimulus control terms: The monkeys were shown to come under stimulus control of individual probe items when the same stimulus sequence was repeated (Experiment 1). They showed relational control upon transfer to a new sequence of new items. However, with repetition of this new item set, stimulus control by the absolute properties of the probe items gradually regained control over performance (Experiment 2). There was only the slightest evidence of absolute control by the list items, even after 100 training sessions to promote

such control. Experiment 3 showed dissociation of relational and absolute stimulus control by poor transfer to novel item sets at the beginning when under control of the absolute properties of the probe stimuli. Control by the relational properties of list and probe stimuli supplanted control by absolute properties of probe stimuli when items were changed on a weekly basis.

Next, the description of the same results in cognitive terms, from the standpoint of the monkeys being strategic, active, hypothesis-testing subjects: The monkeys were shown to adopt an absolute strategy of memorizing the correct responses to the probe items when the same trials were repeated (Experiment 1). They adopted the relational strategy upon transfer to a new sequence of new items, but with repetition of this new item set they gradually readopted the probe-item absolute strategy (Experiment 2). There was only the slightest evidence that they ever adopted a list-item absolute strategy, even after 100 training sessions to promote such a strategy. Experiment 3 showed dissociation of the two strategies by poor transfer to novel item sets at the beginning of the experiment when employing a probe-item absolute strategy. As the stimulus items were repeatedly changed in Experiment 3, there was a reversal of the dominant strategy employed, with relational strategy supplanting the absolute one. Taken together these results show that monkeys will adopt either a relational or an absolute strategy to perform the task (Experiment 3), and also have the potential to retain both strategies and employ either as the situation demands (Experiments 1 and 2).

The difference between these two descriptions is one of emphasis. When strategies are used to describe the behavior, the emphasis is placed upon the role of the subject. When stimulus control is used to describe the behavior, the emphasis is placed upon the controlling aspects of the environment. Both approaches have advantages and disadvantages, and the appropriate description may depend upon the complexity of the particular learning situation to be described.

Strategies imply flexibility in behavior, problem solving, and a contribution of the subject missing in a stimulus control account. Such flexibility was apparent in Experiment 2, when

relational control, as indicated by the good transfer at the beginning of the experiment, immediately followed a situation in which clear absolute control had been exhibited in Experiment 1. Apparently, monkeys can maintain both strategies and select between them as the demands of the situation change. When the task requires that the subject (nonhuman or human) deal with new stimuli frequently, as in Experiment 3, a relational strategy is better suited, as shown by results from monkey and human concept learning experiments (Homa & Chambliss, 1975; Homa, Cross, Cornell, Goldman, & Schwartz, 1973; Homa, Sterling, & Trepel, 1981; Moon & Harlow, 1955; Omohundro, 1981; Overman & Doty, 1980; Wright, Santiago, & Sands, 1984). When the task does not require that the subject deal with new items, an absolute strategy may be better suited for repeated exposures of the same items because this strategy requires less cognitive effort (for humans) than the relational strategy (Hasher & Zacks, 1979). By memorizing the correct responses to individual items, the subject does not have to retrieve the list items from memory and compare them to the probe item. All the subject has to do is to remember which is the correct response (right or left) upon seeing particular items.

Perhaps one reason why little attention has been paid to the ideas of strategies in discrimination learning came from reducing stimuli, responses, tasks, and testing environment to their bare elements. Typically in classical conditioning, S-R association learning, and psychophysics, a discussion of strategies (although they may occur) does not add anything beyond a description in stimulus control terms. Strategic considerations for the nonhumans are limited, because only the solution under study is usually permitted. Responses and stimuli are typically associated in a one-to-one manner producing absolute stimulus learning. Growth of the field of animal cognition, however, has shifted the emphasis from absolute stimulus learning to relational stimulus learning. Tasks having multiple solutions are now being observed with the result that consideration should be given to the strategic contributions of the subjects and to the possibility of viewing nonhumans, like humans, as flexible information processors (Cook, Brown, & Riley, 1985; Krechevsky, 1932).

REFERENCES

- Berryman, R., Cumming, W. W., Cohen, L. R., & Johnson, D. F. (1965). Acquisition and transfer of simultaneous oddity. *Psychological Reports*, *17*, 767-775.
- Bolhuis, J. J., & van Kampen, H. S. (1988). Serial position curves in spatial memory of rats: Primacy and recency effects. *Quarterly Journal of Experimental Psychology*, *40*, 135-149.
- Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A study of thinking*. New York: Wiley.
- Buchanan, J. P., Gill, T. V., & Braggio, J. T. (1981). Serial position and clustering effects in a chimpanzee's "free recall." *Memory & Cognition*, *9*, 651-660.
- Carter, D. E., & Werner, T. J. (1978). Complex learning and information processing by pigeons: A critical analysis. *Journal of the Experimental Analysis of Behavior*, *29*, 565-601.
- Cook, R. G., Brown, M. F., & Riley, D. A. (1985). Flexible memory processing by rats: Use of prospective and retrospective information in the radial maze. *Journal of Experimental Psychology: Animal Behavior Processes*, *11*, 453-469.
- Crowder, R. G. (1976). *Principles of learning and memory*. Hillsdale, NJ: Erlbaum.
- Cumming, W. W., & Berryman, R. (1961). Some data on matching behavior in the pigeon. *Journal of the Experimental Analysis of Behavior*, *4*, 281-284.
- Cumming, W. W., Berryman, R., & Cohen, L. R. (1965). Acquisition and transfer of zero-delay matching. *Psychological Reports*, *17*, 435-445.
- Farthing, G. W., & Opuda, M. J. (1974). Transfer of matching-to-sample in pigeons. *Journal of the Experimental Analysis of Behavior*, *21*, 199-213.
- Gonzalez, R. C., Gentry, G. V., & Bitterman, M. E. (1954). Relational discrimination of intermediate size in the chimpanzee. *Journal of Comparative and Physiological Psychology*, *47*, 385-388.
- Hanson, H. M. (1959). Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, *58*, 321-334.
- Harlow, H. F. (1949). The formation of learning sets. *Psychological Review*, *56*, 51-65.
- Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General*, *108*, 356-388.
- Hearst, E. (1968). Discrimination learning as the summation of excitation and inhibition. *Science*, *162*, 1303-1306.
- Hearst, E., Besley, S., & Farthing, G. W. (1970). Inhibition and the stimulus control of operant behavior. *Journal of the Experimental Analysis of Behavior*, *14*, 373-409.
- Holmes, P. W. (1979). Transfer of matching performance in pigeons. *Journal of the Experimental Analysis of Behavior*, *31*, 103-114.
- Homa, D., & Chambliss, D. (1975). The relative contributions of common and distinctive information on the abstraction from ill-defined categories. *Journal of Experimental Psychology: Human Learning and Memory*, *1*, 351-359.
- Homa, D., Cross, J., Cornell, D., Goldman, D., & Schwartz, S. (1973). Prototype abstraction and classification of new instances as a function of number of instances defining the prototype. *Journal of Experimental Psychology*, *101*, 116-122.
- Homa, D., Sterling, S., & Trepel, L. (1981). Limitations of exemplar-based generalization and the abstraction of categorical information. *Journal of Experimental Psychology: Human Learning and Memory*, *7*, 418-439.
- Honig, W. K., Boneau, C. A., Burstein, K. R., & Pen-nypacker, H. S. (1963). Positive and negative generalization gradients obtained after equivalent training conditions. *Journal of Comparative and Physiological Psychology*, *56*, 111-116.
- Honig, W. K., & Urciuoli, P. J. (1981). The legacy of Guttman and Kalish (1956): Twenty-five years of research on stimulus generalization. *Journal of the Experimental Analysis of Behavior*, *36*, 405-445.
- Hull, C. L. (1943). *Principles of behavior*. New York: Appleton-Century-Crofts.
- Hulse, S. H., Fowler, H., & Honig, W. K. (1978). *Cognitive processes in animal behavior*. Hillsdale, NJ: Erlbaum.
- Jackson, W. J., & Pegram, G. V. (1970). Acquisition, transfer, and retention of matching by rhesus monkeys. *Psychological Reports*, *27*, 839-846.
- Jitsumori, M., Wright, A. A., & Cook, R. G. (1988). Long-term proactive interference and novelty enhancement effects in monkey list memory. *Journal of Experimental Psychology: Animal Behavior Processes*, *14*, 146-154.
- Kendler, T. S. (1950). An experimental investigation of transposition as a function of the difference between training and test stimuli. *Journal of Experimental Psychology*, *40*, 552-562.
- Kendrick, D. F., Rilling, M., & Denny, M. R. (1986). *Theories of animal memory*. Hillsdale, NJ: Erlbaum.
- Kesner, R. P. (1985). Correspondence between humans and animals in coding of temporal attributes: Role of hippocampus and prefrontal cortex. *Annals of the New York Academy of Sciences*, *444*, 122-136.
- Kesner, R. P., & Novak, J. M. (1982). Serial position curve in rats: Role of the dorsal hippocampus. *Science*, *218*, 173-175.
- Köhler, W. (1918/1939). Nachweis infacher struktur-funktionen beim schimpansen und beim haushuhn: Über eine neue method zur untersuchung die bunten farbensystems. *Abhandlungen der Preussischen Akademie der Wissenschaften*, *2*, 1-101. Reprinted in translation as "Simple structural functions in the chimpanzee and in the chicken," in W. D. Ellis (Ed., 1939), *A source book of gestalt psychology* (pp. 217-227). New York: Harcourt, Brace.
- Köhler, W. (1925). *The mentality of apes* (2nd rev. ed.; E. Winter, Trans.). New York: Harcourt, Brace.
- Krechevsky, I. (1932). 'Hypotheses' in rats. *Psychological Review*, *39*, 516-532.
- Lashley, K. S. (1942). An examination of the "continuity theory" as applied to discrimination learning. *Journal of General Psychology*, *26*, 241-265.
- Lawrence, D. H., & DeRivera, J. (1954). Evidence for relational transposition. *Journal of Comparative and Physiological Psychology*, *47*, 465-471.
- Moon, L. E., & Harlow, H. F. (1955). Analysis of oddity learning by rhesus monkeys. *Journal of Comparative Physiological Psychology*, *48*, 188-194.
- Moye, T. B., & Thomas, D. R. (1982). Effects of mem-

- ory reactivation treatments on postdiscrimination generalization performance in pigeons. *Animal Learning & Behavior*, **10**, 159–166.
- Omohundro, J. (1981). Recognition vs. classification of ill-defined category exemplars. *Memory and Cognition*, **9**, 324–331.
- Overman, W. H., Jr., & Doty, R. W. (1980). Prolonged visual memory in macaques and man. *Neuroscience*, **5**, 1825–1831.
- Premack, D. (1978). On the abstractness of human concepts: Why it would be difficult to talk to a pigeon. In S. H. Hulse, H. Fowler, & W. K. Honig (Eds.), *Cognitive processes in animal behavior* (pp. 423–451). Hillsdale, NJ: Erlbaum.
- Premack, D. (1983a). Animal cognition. *Annual Review of Psychology*, **34**, 351–362.
- Premack, D. (1983b). The codes of man and beasts. *Behavioral and Brain Sciences*, **6**, 125–167. (Includes commentary)
- Rescorla, R. A. (1988). Pavlovian conditioning: It's not what you think it is. *American Psychologist*, **43**, 151–160.
- Reynolds, G. S. (1961). Behavioral contrast. *Journal of the Experimental Analysis of Behavior*, **4**, 57–71.
- Riley, D. A. (1968). *Discrimination learning*. Boston: Allyn & Bacon.
- Rilling, M. (1977). Stimulus control and inhibitory processes. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 432–480). Englewood Cliffs, NJ: Prentice-Hall.
- Roberts, W. A., & Kraemer, P. J. (1981). Recognition memory for lists of visual stimuli in monkeys and humans. *Animal Learning & Behavior*, **9**, 587–594.
- Roitblat, H. L., Bever, T. G., & Terrace, H. S. (Eds.). (1984). *Animal cognition*. Hillsdale, NJ: Erlbaum.
- Sands, S. F., & Wright, A. A. (1980a). Primate memory: Retention of serial list items by a rhesus monkey. *Science*, **209**, 938–940.
- Sands, S. F., & Wright, A. A. (1980b). Serial probe recognition performance by a rhesus monkey and a human with 10- and 20-item lists. *Journal of Experimental Psychology: Animal Behavior Processes*, **6**, 386–396.
- Santi, A. (1978). The role of physical identity of the sample and correct comparison stimulus in matching-to-sample paradigms. *Journal of the Experimental Analysis of Behavior*, **29**, 511–516.
- Santi, A. (1982). Hue matching and hue oddity in pigeons: Is explicit training not to peck incorrect hue combinations a sufficient condition for transfer? *Psychological Record*, **32**, 61–73.
- Santiago, H. C., & Wright, A. A. (1984). Pigeon memory: Same/different concept learning, serial probe recognition acquisition, and probe delay effects on the serial-position function. *Journal of Experimental Psychology: Animal Behavior Processes*, **10**, 498–512.
- Spence, K. W. (1936). The nature of discrimination learning in animals. *Psychological Review*, **43**, 427–449.
- Spence, K. W. (1937). The differential response in animals to stimuli varying within a single dimension. *Psychological Review*, **44**, 430–444.
- Staddon, J. E. R. (1983). *Adaptive behavior and learning*. Cambridge: Cambridge University Press.
- Weiss, S. J., & Schindler, C. W. (1981). Generalization peak shift in rats under conditions of positive reinforcement and avoidance. *Journal of the Experimental Analysis of Behavior*, **35**, 175–185.
- Wright, A. A. (in press). Concept learning by monkeys and pigeons. In M. Corballis, K. G. White, & W. Abraham (Eds.), *Memory mechanisms: A tribute to G. V. Goddard*. Hillsdale, NJ: Erlbaum.
- Wright, A. A., Cook, R. G., Rivera, J. J., Sands, S. F., & Delius, J. D. (1988). Concept learning by pigeons: Matching-to-sample with trial-unique video picture stimuli. *Animal Learning & Behavior*, **16**, 436–444.
- Wright, A. A., Santiago, H. C., & Sands, S. F. (1984). Monkey memory: Same/different concept learning, serial probe acquisition, and probe delay effects. *Journal of Experimental Psychology: Animal Behavior Processes*, **10**, 513–529.
- Wright, A. A., Santiago, H. C., Sands, S. F., Kendrick, D. F., & Cook, R. G. (1985). Memory processing of serial lists by pigeons, monkeys, and people. *Science*, **229**, 287–289.
- Wright, A. A., Santiago, H. C., Sands, S. F., & Urcuioli, P. J. (1984). Pigeon and monkey serial probe recognition: Acquisition, strategies, and serial position effects. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 353–374). Hillsdale, NJ: Erlbaum.
- Wright, A. A., Santiago, H. C., Urcuioli, P. J., & Sands, S. F. (1984). Monkey and pigeons acquisition of same/different concept using pictorial stimuli. In M. L. Commons, R. J. Herrnstein, & A. R. Wagner (Eds.), *Quantitative analyses of behavior: Vol. 4. Discrimination processes* (pp. 295–317). Cambridge, MA: Ballinger.
- Wright, A. A., & Watkins, M. J. (1987). Animal learning and memory and their relation to human learning and memory. *Learning and Motivation*, **18**, 131–146.
- Zeiler, M. D. (1963). The ratio theory of intermediate size discrimination. *Psychological Review*, **70**, 516–533.
- Zentall, T., & Hogan, D. (1974). Abstract concept learning in the pigeon. *Journal of Experimental Psychology*, **102**, 393–398.

Received November 14, 1988

Final acceptance July 7, 1989