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Conditional discrimination learning of two-object-pairs by rats

Md. Abu Bokor SIDDIK^{1),2)} and Tohru TANIUCHI^{1),2)a)}

Abstract Two rats were trained in a successive same/different discrimination task, where pairs of simultaneously presented objects were used as discriminative cues for conditional place discrimination. Depending on the same or different relationship between the two objects in a pair, responses to the right or left alley were differentially reinforced. In the first acquisition phase, responses to a task of AA/BB vs. AB/BA did not exceed chance. To make the task easier, pair BB was withdrawn in Phase 2 (AA vs. AB/BA), and, as a result, both rats achieved learning criterion. Rat 1 also reliably learned the Phase 3 task, where pair BB was reintroduced (AA/BB vs. AB/BA). Although Rat 1 learned the Phase 3 task, where a single item feature could not be an effective discriminative cue, the data suggest that rats learn some item-specific configural information for item pairs. Given that the experimental method of the present study achieved basic discrimination learning of object pairs by rats, it may be suitable for a S/D discrimination learning experiment using object pairs. Factors that may facilitate relational learning in rats are discussed.

Keywords rats, same/different concept, abstract concept, item-specific learning, relational learning

In recent years, the importance of understanding animal conceptual behavior has gradually become one of central topics of the comparative study of intelligence (Cook, 2001). Abstract concepts are at the root of higher order cognitive processing (e.g., language and mathematics). There are several types of abstract concepts, such as number, category, and relationship. The abstract concept of number is the numerical property of stimuli and could be applied to a variety of stimuli, regardless of their physical features. The abstract concept of category may be divided in two types, one being a natural concept, as when we categorize a novel fish as a fish or a novel tree as a tree. Given that members of a natural category share some common physical features, this natural concept is sometimes defined as non-abstract. Conversely, there are some abstract categories that are defined by function. For example, the concept of “food” or “tool” is defined by its function and members of these cat-

egories do not necessarily share any physical similarity. Finally, a relational concept is defined as an abstract relationship among stimuli, such as sameness, difference, relative magnitude (less than or greater than), and so on. Therefore, relational concepts do not have specific members; they simply describe abstract relationships among stimuli.

The relational same/different (S/D) concept is the ability to identify a stimulus as either the same or different from other stimuli. The S/D concept discriminates an abstract relationship, regardless of the specific physical features of the stimuli. For example, in the case of two red circles, we can describe these stimuli as “same”. But in the case of two green squares, the specific physical features (colors and shapes) of the component stimuli are completely different from those of the first example. But we can apply the identical relational concept of “same” to describe each of these two cases. To learn the S/D concept, subjects need to recognize not only several specific features of the stimuli (color, shape, size, etc.) but also the abstract relationship between the stimuli (sameness or difference). If animals learn only specific features in S/D

¹⁾ Graduate School of Human and Socio-Environmental Studies, Kanazawa University

²⁾ These authors contributed equally to this work.

a) E-mail: tohruta@staff.kanazawa-u.ac.jp

discrimination tasks, their learning will never transfer to novel pairs because the novel pairs of stimuli might not share common specific features with the training pairs. However, if they learn the abstract S/D relationship among stimuli, they will be able to apply it to novel pairs. Therefore transfer of S/D discrimination to novel stimuli can be interpreted as evidence of the abstract S/D concept.

A seminal article by David Premack (1978), "On the abstractness of human concepts: Why it would be difficult to talk to a pigeon", attracted the attention of comparative psychologists to S/D concept learning because Premack claimed that non-primates might not be able to learn the S/D abstract concept. Empirically, S/D tasks were successfully learned by primates under some conditions (Premack, 1978; Shyan, Wright, Cook et al., 1987; Oden, Thompson, & Premack, 1990), whereas results for S/D learning tasks had been limited in non-primates. Although early research showed some experimental evidence of S/D discrimination by pigeons (e.g., Zentall & Hogan, 1974; Urcuioli & Nevin, 1975), Premack (1978, 1983) criticized the procedures of these studies and proposed a non-conceptual explanation. Reviewing early findings, Premack (1978, 1983) concluded that abstract concept learning might be limited to primates, thus stimulating avian researchers, who devised ingenious experimental techniques as a response to Premack's criticism and reported reliable evidence of S/D concept learning by birds since the 1990's (e.g., Cook, Kelly, & Katz, 2003; Blaisdell & Cook, 2005; Wright & Katz, 2006). In the past 30 years, much research on S/D concept learning using monkeys, e.g., baboons (Wasserman, Fagot, & Young, 2001), rhesus (Katz, Wright & Bachevalier, 2002), and capuchins (Wright, Rivera, Katz et al., 2003), and birds, e.g., parrots (Pepperberg, 1987) and pigeons (Katz & Wright, 2006), has been conducted, demonstrating clear evidence of immediate transfer of the conceptual S/D relationship to novel stimuli.

Little research has been conducted on abstract concept learning by rodents and it failed to provide clear evidence of learning abstract relational con-

cepts. Thus it is still unclear whether rats have the cognitive ability to acquire the abstract S/D concept. For example, Thomas & Noble (1988) trained rats with oddity discrimination tasks in which rats were required to discriminate the single odd item from two identical items. They trained rats with 300 different combinations sequentially but no improvement of performance was observed. Why did rats fail to acquire oddity concept learning? One possibility is that Thomas & Noble (1988) changed stimulus pairs every twenty trials, regardless of the rats' performance. Therefore, the rats could not learn the rule to solve these learning tasks. Another possibility is the sequential training of tasks. They presented a single task at a time and then shifted to the next task (e.g., AAB to CCD). A single task could be solved simply by approaching a specific item. For example, task AAB could be solved by responding to item B. The same strategy was effective for next task, CCD, where responding to item D led to the solution. Therefore, in a sequential training procedure, learning by try-and-error to respond to a specific item can be a simple and effective learning strategy and abstract relational learning seems unnecessary.

In the present study, we trained rats in a conditional place discrimination task where the S/D relationship between two item objects could be discriminative cues. We first presented the rats with the concurrent discrimination task of AA/BB vs. AB/BA. Because these tasks were given to rats concurrently in a daily session, the existence of a specific single item cue, that is, A or B, could not be an effective discriminative cue. We expected that concurrent training of multiple tasks would facilitate learning of abstract S/D relationships between items. If rats could learn the abstract S/D relationship between two items, transfer of learning to novel pairs would be expected.

Method

Subjects Two experimentally naive Long Evans hooded rats, about 240 days old, were used. They were individually housed with 12 hr light-dark cy-

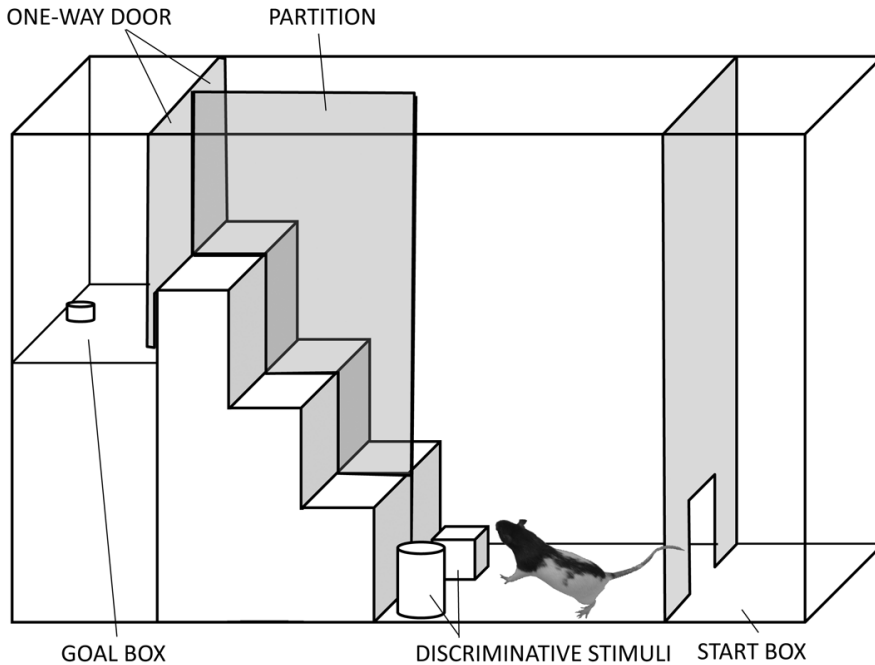


Figure 1 Apparatus used in the present experiment.

cles (light phase 9:00-21:00). Experiments took place during the light phase. They were fed 14 g of food daily except for experimental rewards. Access to water was unrestricted except during experimental sessions.

Apparatus A discrimination box was used. The apparatus, 112 cm long, 61 cm high and 23.2 cm wide, consisted of a start box, a runway, two separate stairs, and a goal box (Figure 1). The main parts of the apparatus were made of wood and painted flat gray. Both the start box and the goal box were 18 cm long and 23.2 cm wide. The runway was 35 cm long and 23.2 cm wide. Rats entered the runway from the start box through an opening (10 cm high and 10 cm wide) in the wall between the start box and runway. Stimulus objects were set in front of the bottom step of the stairs. The stairs consisted of three 15 cm high and 10 cm long steps. Rats could enter the goal box by pushing one-way doors at the top of each stairway. At the end of the goal box, a food cup, 1.5 cm in diameter and 0.5 cm in depth, was placed and 20

mg of food pellets was used as a reward.

Discriminative Stimuli Discriminative stimuli were selected from clothespins, transparent bottles, magnifying glasses, silver objects, and brown bottles (Figure 2). For Rat 1, stimulus A was a clothespin, stimulus B was a transparent bottle, and stimulus C was a magnifying glass. For Rat



Figure 2 A photograph of item objects.

2, stimulus A was a brown bottle and stimulus B was a silver object.

Procedure During the first 10 days, each rat received daily handling for 7 min. On Days 11-17, each rat was given 10 min individual exploration of the apparatus from which the stairs were completely removed. Ten food pellets were scattered over the apparatus and the food cup. Rats were allowed to eat these food pellets during exploration. Shaping of running response was started on Day 18 and continued for 30 days. Rats were brought into the experimental room by their home cage. At the beginning of shaping, there were no stairs in the apparatus. Rats were put into the start box and allowed to go to the goal box directly and to remain there until they consumed two food pellets from the food cup. Then a low barrier was introduced and rats were trained to go to the goal box by climbing over the barrier. The barrier was made higher until it reached its full size of three stepped stairs. Each stairway was used for the same number of trials by a forced-choice procedure with 24 trials given daily. When rats could climb the stairs reliably, discriminative stimuli were introduced from Day 49 and S/D discrimination training began. The first S/D task was AA/BB vs. AB/BA (Phase 1). The first character of a pair (e.g., AB) represents the left stimulus object (A) and the second character represents the right one (B). When the two objects were identical (e.g., AA), responding to the left stairway was reinforced by opening the goal door and allowing the rat to consume two food pellets. When the two objects were different (e.g., AB), responding to the right stairway was reinforced. In the case of an incorrect response, the goal door was locked and the rat was removed immediately from the stairs to the home cage without reward. Order of presentation of same and different trials was determined by the Fellows series (Fellows, 1967). Presentation order within the same (AA and BB) or different set (AB and BA) was determined randomly per two trials. Rats were trained in a daily session of 48 trials in total, i.e., 24 same and 24 different trials. A 1 min inter-trial interval (ITI) separated each

trial. The learning criterion was 75% correct on two consecutive days of sessions. Due to considerations mentioned in the Results section, pair BB was withdrawn in Phase 2 and the task became AA vs. AB/BA. In Phase 3, pair BB was reintroduced and the task became AA/BB vs. AB/BA again. In Phase 4, stimulus C was added and AA/BB/CC vs. AB/BA/AC/BC/CA/CB training was given. Thus, AA, BB, and CC were presented on eight trials and AB, BA, AC, BC, CA, and CB were presented four times daily.

Results

Figure 3 shows the rats' performance in the experimental sessions, where 62.5% correct (30/48) represents a statistically significant performance in a session ($p < .05$, binomial test, one-tailed). In Phase 1 (AA/BB vs. AB/BA), the rats' performance was at around chance for 11 sessions and there was no sign of improvement. Therefore, to make the task easier, pair BB was withdrawn in Phase 2 (AA vs. AB/BA). Then their performance improved gradually and reached learning criterion after 16 sessions for Rat 1 and 47 sessions for Rat 2 (Because of experimenter error, Rat 2 was shifted to Phase 3 after attaining three consecutive 75% correct sessions). When pair BB was reintroduced in Phase 3 (AA/BB vs. AB/BA), although the rats' performance was at above the significant level during first session for Rat 1 and three sessions for Rat 2, it subsequently deteriorated to chance. Table 1 shows the rats' performance on the first five sessions of Phase 3 for the previously trained pairs AA, AB, BA and newly introduced pair BB. Detailed analysis revealed that the initial significant performances were due to enduring correct responses to pairs AA, AB, BA that had been trained continuously from Phase 2, whereas poor performance below the chance level was shown for the newly introduced pair BB. As performance on trial BB increased to the chance level, trials of AA, AB, BA conversely deteriorated to chance ($r = -.91$ and $-.46$ for Rat 1 and Rat 2, respectively). Although Rat 2 could not learn the Phase 3 task within 32

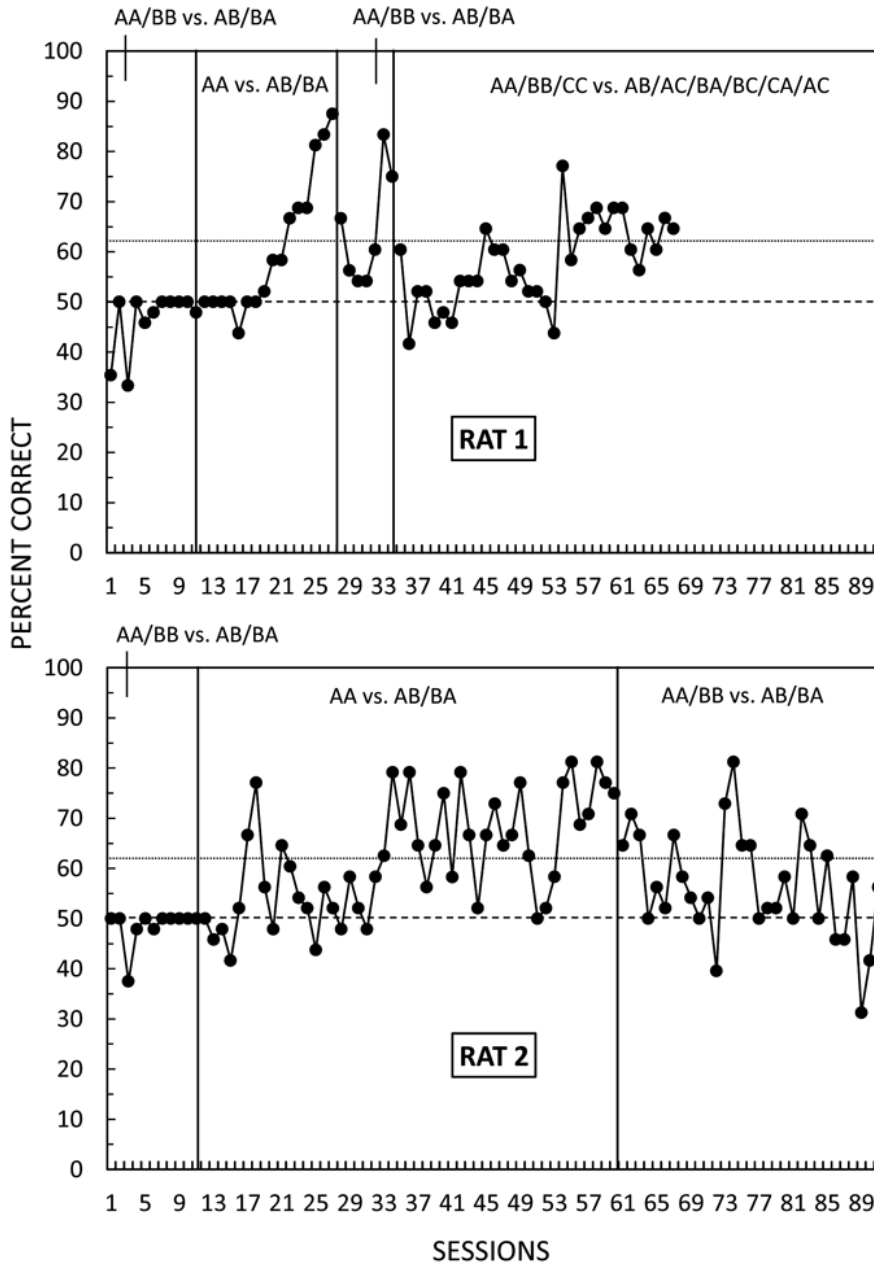


Figure 3 Percentage of correct responses in each training phase. Broken lines represent a chance level (50%) and dotted lines represent a statistically significant performance level (62.5% correct, $p < .05$) in a session.

sessions, Rat 1 recovered its performance quickly and attained the learning criterion within seven sessions. When object C was added in Phase 4 (AA/BB/CC vs. AB/BA/AC/BC/CA/CB), how-

ever, Rat 1's performance deteriorated to chance. Although Rat 1 sometimes performed significantly better than chance, its performance was not stable and did not meet the learning criterion.

Table 1 Percentage of correct responses on first five sessions of Phase 3 for previously trained pairs (AA, AB, and BA) and newly introduced pair (BB).

PHASE 3		TOTAL	AA, AB, BA	BB
SESSION 1	RAT 1	66.67	83.33	16.67
	RAT 2	64.58	77.78	25.00
SESSION 2	RAT 1	56.25	69.44	16.67
	RAT 2	70.83	83.33	33.33
SESSION 3	RAT 1	54.17	55.56	50.00
	RAT 2	66.66	83.33	16.67
SESSION 4	RAT 1	54.17	55.56	50.00
	RAT 2	50.00	52.78	41.67
SESSION 5	RAT 1	60.42	72.22	25.00
	RAT 2	56.25	75.00	0.00

Discussion

For the initial training set (AA/BB vs. AB/BA), the performance of both rats was at around the chance level and did not improve. Because the task of the first phase seemed to be too difficult for the rats, pair BB was withdrawn in Phase 2 to make the task easier (AA vs. AB/BA). As a result, both rats attained the learning criterion of Phase 2. Although Rat 2 could not learn the next task in Phase 3, where pair BB was introduced again (AA/BB vs. AB/BA), Rat 1 learned this task reliably and attained the learning criterion. Attainment of the easier task in Phase 2 might contribute to learning the more difficult task in Phase 3.

There are three possible processes in learning the tasks in this present experiment. The first possibility is abstract relationship learning, where abstract S/D relationships between two object stimuli are represented and used as discriminative cues. However, the results of Phase 4 do not support this possibility. When novel item C was added to the task in Phase 4, the performance of Rat 1 declined to chance level. If Rat 1 had learned to respond to the abstract S/D relationship of the pairs, this learning should have transferred to the task in Phase 4, where novel item C was added (AA/BB/CC vs. AB/BA/AC/BC/CA/CB). Therefore, this suggests that Rat 1 was not able to respond to the Phase 3 task (AA/BB vs. AB/BA) on a conceptual basis.

The second possibility is to learn a specific single bit of information so that the absence or presence of a single item can be used as an effective discriminative cue. For example, the presence or absence of item B could be an effective discriminative cue in Phase 2 (AA vs. AB/BA). Rats could respond to pairs that did not contain item B as “same” and pairs that contained item B as “different”. However, this learning strategy was not effective in Phase 3, where not only different pairs (AB/BA) but also the same pairs (AA/BB) contained items A and B. Therefore, the acquisition of the task in Phase 3 by Rat 1 cannot be interpreted in terms of single specific-information learning.

The third possibility is that rats might learn the configuration of two-object stimuli as discriminative cues. It has been reported that pigeons learned configurations of two photographs out of eight photographs as unique item-specific discriminative cues (e.g., Katz & Wright, 2006). This may be true for Rat 1's performance in Phase 3, where it could solve the task by remembering four different configurations (AA, BB, AB and BA) and learning to differentially respond to these configurations. That is, Rat 1 might follow if-then rules to learn the Phase 3 task, “if the presented pair was AA or BB, respond to left stairs, and if the pair was AB or BA, respond to the right stairs”. Because these if-then rules could not be applied to novel configuration, Rat 1's performance deteriorated to chance when the task was changed from Phase 3 to Phase 4.

In Phase 2 (AA vs. AB/BA), both rats learned to respond correctly to the pairs of objects. But they seemed to learn this task on the basis of single item-specific information. This interpretation is supported by the results of the shift from Phase 2 to Phase 3. Analysis of initial significant performances on Phase 3 revealed both rats had a tendency to respond to BB below the chance level (responded as “different”), whereas they responded correctly to AA, AB, and BA. This is exactly what the if-then rule, based on existence of item B, predicts. As performance on trials of BB increased to chance, that on trials of AA, AB, and BA deteriorated to chance. Rats might have abandoned the if-then rule based on the existence of B because responding based on the if-then rule always received non-reinforcement on the BB trial. Abandonment of the if-then rule explains the reason for the negative correlation of performance between BB and AA/AB/BA on initial trials of Phase 3.

Both rats’ performance completely deteriorated to the chance level after pair BB was introduced in Phase 3 (AA/BB vs. AB/BA). If the rats had learned the Phase 2 task (AA vs. AB/BA) on the basis of an abstract S/D relationship, they should have been able to transfer this learning to the next phase (AA/BB vs. AB/BA). This result also discounts the possibility of configural learning. If they had accomplished the Phase 2 task by learning three unique configurations (AA vs. AB/BA), they should have responded to the pair BB randomly, at around chance, but not at below chance. Thus the initial tendency to respond to pair BB below the chance level is also inconsistent with the configural learning explanation. Therefore, the result contingent with the shift from Phase 2 to Phase 3 seems to be in favor of the single item-specific learning explanation.

We might ask why Rat 1 learned the single item feature in Phase 2 and the configuration of two objects in Phase 3. Given that learning a single item feature requires learning about just that single feature, whereas configural learning requires encoding multiple items and remembering multiple configu-

rations, single feature learning seems to require simpler information processing and less memory load for learning than configural learning. Also we may explain the relative ease of configural learning versus abstract S/D concept learning for rats in terms of the demands of abstract encoding. That is, configural learning requires encoding of concrete item-specific information, whereas abstract S/D concept learning requires encoding abstract relational information between items. Considering the abundant evidence of concrete or absolute feature learning and the limited evidence of abstract or relative feature learning in rats (e.g., Thomas & Noble, 1988), configural learning that requires only processing of concrete features of stimuli seems to be next strategy for learning. Hence, when there is no effective single item feature cue in a task, rats may adopt configural learning.

However, the memory load required for configural learning will increase as a function of the number of configurations to be learned. Conversely, if rats can learn the abstract S/D relationship between items, they can reduce this increased memory load because the abstract S/D rules can be applied for all pairs of items appropriately. Rats may select a learning strategy based on such a hierarchy of learning processes to learn two-item S/D discrimination tasks.

There is experimental evidence to support this hierarchical strategy hypothesis. First, Thomas & Noble (1988) trained rats with oddity discrimination tasks, where a single task (e.g., AAB) was used per session and the task was then shifted to next single one (e.g., CCD), and they failed to prove the abstract relational oddity concept. Therefore, approaching a single positive stimulus was an effective learning strategy.

Then, Elmore, Wright, Rivera et al. (2009) trained pigeons on a two-item S/D discrimination task and suggested that one of the three pigeons learned item-specific configural cues given that the pigeons learned the acquisition task, where no single item-specific cue was available, but showed chance level performance to novel stimulus pairs

on test trials. This finding suggests that animals can learn two-item conditional discrimination, not based on abstract S/D relationships between the items, but by responding to an item-specific configuration as discriminative cues. Even when a single item-specific cue is not available, animals seem to learn item-specific configurations if there are a small number of stimuli. When a small number of stimuli are used for training, it may not be difficult for non-primate animals to learn and retain specific configurations in long-term memory. In other words, when a stimulus set consists of a small training set, non-primate animals seem to learn item-specific information, even if they have the ability to learn abstract S/D relationships.

However, when there are a large number of stimuli and, therefore, stimulus pairs, animals seem to search for abstract S/D relationships that can be applied to all stimulus pairs. There is clear evidence to support that the degree of transfer to novel stimulus pairs is correlated with the number of stimuli used in training. Wright and Katz (2006) showed that a smaller set of training stimuli led to item-specific rote learning and a larger set of exemplars prompted abstract S/D concept learning. They demonstrated that rhesus monkeys, capuchin monkeys, and pigeons showed chance transfer performance of S/D discrimination of two colored pictures following acquisition training with eight stimuli. When the training set size was increased to 32 stimuli, monkeys showed evidence of partial S/D concept learning but pigeons showed no sign of transfer to the novel stimuli. With the further expansion of the training set size to 128 stimuli, monkeys showed good performance with novel test stimuli, comparable to their performance on the training stimuli, and pigeons showed partial S/D concept learning. Pigeons needed 256 stimuli to fully acquire the abstract S/D concept. These findings suggest that if rats have an ability to learn abstract S/D relationships between stimuli and if we can train them with a large number of stimuli, they may show evidence of transfer to novel pairs of stimuli.

It has been shown that increasing response cost leads to good performance in some discrimination tasks by making rats' response criterion stricter (e.g., Brown & Huggins, 1993; Brown & Lesniak-Karpiak, 1993; Fortin, Wright, & Eichenbaum, 2004). That is, when some effort is required for discriminative responses, rats seem to give their attention to discriminative stimuli and choose their response more carefully. In the present study, we also imposed response cost on discriminative responses by requiring rats to climb over stairways to enter the goal box. Although increased response cost might contribute to discriminative performance in the present study, such an effect could not be evaluated appropriately because there is no adequate control condition where a particular response cost was not imposed. To improve basic performance of discrimination learning of object pairs in rats, factors that affect response criterion or attention to the discriminative stimuli should be examined further in terms of apparatus and training procedure.

We must improve our protocol for testing the ability of rats to learn the abstract S/D relationship by eliminating access to single item cues, by increasing the stimulus set size to facilitate encoding of the abstract S/D relationship, and by increasing the number of items presented at one time so as to make the quantitative S/D relationship more salient. Knowledge about the presence or absence of cognitive ability for S/D concept learning in rats would contribute to elucidating the phylogenetic origins of information processing of abstract relationships among stimuli.

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