

*FORMATION OF THE SAMENESS-DIFFERENCE
CONCEPT BY JAPANESE MONKEYS FROM A
SMALL NUMBER OF COLOR STIMULI*

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Japanese monkeys were trained to form the sameness-difference concept. In Experiment 1, four monkeys were trained with two colors to discriminate matching stimulus pairs from nonmatching pairs by reinforcing only lever-pressing responses to matching pairs with a variable-interval schedule. Three monkeys showed successful transfer of this discrimination to two new colors, thus demonstrating that some Japanese monkeys are able to form this relational concept from a minimum number of stimuli. In Experiment 2, two monkeys were trained, in a Yes/No procedure with three colors, to press one lever under matching pairs and another lever under nonmatching pairs. Poor transfer performances to three new colors suggest that simultaneously establishing two different response patterns to matching and nonmatching pairs is ineffective in forming the concept. In Experiment 3, the amount of transfer to three new colors after mastering a standard three-color matching-to-sample task was compared with that of a modified task in which correct responses were reinforced with a within-trial variable-interval schedule. All three monkeys showed greater transfer with the modified procedure. The results suggest that the variable-interval schedule adopted within trials is effective in forming the sameness-difference concept.

Key words: concept formation, sameness-difference concept, matching to sample, conditional discrimination, abstraction, key press, lever press, monkeys

The formation of the sameness-difference concept by an animal can be objectively shown by the fact that the general relation of sameness or difference of stimuli comes to control the animal's behavior as a discriminative stimulus. The experimental demonstration of such relational control requires not only accurate performance in a task incorporating sameness-difference judgments with regard to several stimuli, but also successful transfer of that performance to new stimuli. Previous work has demonstrated that some nonhuman animals are able to form this relational concept: monkeys with oddity learning-set procedures

(e.g., Levine & Harlow, 1959; Shaffer, 1967; Thomas & Boyd, 1973; Thomas & Kerr, 1976); chimpanzees using a simultaneous discrimination of matching pair and nonmatching pair with transfer training (e.g., Robinson, 1955); and dolphins with matching-to-sample learning-set procedures (e.g., Herman & Gordon, 1974). These studies suggest that the sameness-difference relationship of stimuli comes to control the animals' behavior if the animals are trained with a large number of instances that have a common aspect based on sameness-difference.

However, the sameness-difference relationship can be easily abstracted, at least by humans, from a set of instances constructed with a minimum number of stimuli (e.g., AA, BB, AB, and BA). Premack (1978) proposed that the animal's behavior is more or less concurrently controlled by two factors: the absolute values of the stimuli and the general relationships of the stimuli. As he suggested, species differences in the ability for abstraction can be measured by the tendencies of the relational and absolute (or stimulus-specific) aspects of stimuli to control the animal's operant behavior. From this point of view, comparative studies on the ability for abstraction in ani-

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imals may not need to use a large number of stimuli. Rather, it is more important to examine which aspects of the stimuli—that is, general relationships of stimuli or stimulus-specific aspects—are apt to control the animal's behavior when a small number of stimuli are used for establishing conceptual behavior. In other words, the important question is: How abstract is the animal's apparently conceptual behavior?

Several previous studies with monkeys attempted to answer this question by examining transfer of the animals' matching-to-sample discriminations to new stimuli (Fujita, 1982; Fujita, 1983; Jackson & Pegram, 1970a, 1970b; Kojima, 1979; Mello, 1971). All these studies except one (Jackson & Pegram, 1970a) failed to demonstrate good transfer and thus consistently suggested that monkeys barely formed sameness-difference concept after matching-to-sample training with a few stimuli.

The same question has been examined much more actively with pigeons as subjects. Carter and Werner (1978) reviewed the literature and concluded that pigeons were unable to form a sameness-difference concept after matching-to-sample training. In addition, Carter and Taten (Note 1) failed to demonstrate concept formation using a learning-set procedure.

What is confusing, however, is that several studies with pigeons that employed modified matching to sample reported somewhat strong stimulus control by sameness-difference: Honig (1965), using a free-operant Yes/No procedure; Malott and Malott (1970) and Malott, Malott, Svinicki, Kladder, and Ponicki (1971), in a free-operant Go/No go procedure; and Urcuioli (1977), Urcuioli and Nevin (1975), and Zentall and Hogan (1978), with something like trialwise Go/No go procedures. Thus the previous failure to demonstrate transfer in monkeys may be due to some procedural defects included in matching to sample. It may be possible for monkeys to form the sameness-difference concept from, for example, as few as two stimuli if the appropriate procedure is adopted.

Experiment 1 of the present study attempted to determine whether Japanese monkeys are able to form the sameness-difference concept from a small number of stimuli. Based

on the results of Experiment 1, Experiments 2 and 3 examined the effects of some procedural variables on establishing strong stimulus control by sameness-difference.

EXPERIMENT 1

The most striking evidence for concept formation by pigeons was provided by Malott and Malott (1970) and Malott et al. (1971). A circular key was vertically divided into two equal areas. Pecking the key was reinforced according to a variable-interval schedule only when colors on both areas matched (or non-matched). Though training included as few as two colors, successful transfer to two new colors was obtained without reinforcement of the pigeons' transfer responses. Although Carter and Werner (1978) suggested that the pigeons might have discriminated circles (when colors on both areas matched) from two semi-circles (when colors did not match), this free-operant Go/No go procedure seems to be very efficient for concept formation.

The following experiment trained Japanese monkeys in a similar free-operant procedure to form a sameness-difference concept from two stimuli, in order to reevaluate their ability for abstraction. Two stimuli were independently presented on two keys to avoid the "circle-semicircle" problem.

METHOD

Subjects

Four young Japanese monkeys (*Macaca fuscata fuscata*) served. Two 3-year-old subjects (T373, male, and O393, female) had some laboratory experience, but they had not experienced any discrimination task that incorporated a sameness-difference judgment. The other two 5-year-old male subjects (T320 and K371) had been trained in a higher-order conditional discrimination task consisting of a matching-to-sample and an oddity-from-sample task with red and purple in the previous study (Fujita, 1983). However, neither of the two subjects showed any transfer to new colors in that study. In addition, they had not been trained to match colors other than red and purple, which were used in this experiment as baseline stimuli. Body weights of the four subjects were maintained at approximately 95% of their free-feeding weights.

Apparatus

The experimental chamber (70 cm by 70 cm by 70 cm) was located in a dark room. White noise was used to mask external sounds. A houselight was at the top of one wall of the chamber and a feeder tray was at the bottom of the wall. The experimental panel (Figure 1) was attached to the wall. Five transparent acrylic keys (35 mm wide and 50 mm high) were arranged horizontally in the center of the panel, each key separated 55 mm, center to center. A barrier, which projected 20 mm inside, was 10 mm below these keys. Three levers (35 mm wide and 17 mm long) were attached 20 mm below the barrier. Keys were respectively labeled Key 1, Key 2, Key 3, Key 4, and Key 5, from left to right, and each lever was similarly labeled Lever 1, Lever 2, and Lever 3. In-line projectors (Industrial Electronics Engineers) installed behind these five keys could present seven colors as stimuli (red: Kodak No. 25; purple: Fuji SP 6; blue: Kodak No. 47A; blue-green: Fuji BPB50; yellowgreen: Fuji BPB55; yellow: Fuji SC50; white: no filter) and one figure (white dot). Each lever could be illuminated independently by a 24-V tungsten lamp through a slit just above the lever. A piece of food (raisins or soybeans according to each subject's taste) could be delivered by a universal feeder (Davis Scientific Instruments) into the feeder tray as a reinforcer. A 24-V tungsten lamp could illuminate the tray. Two kinds of buzzer (the reinforcement buzzer and the timeout buzzer) were outside the chamber.

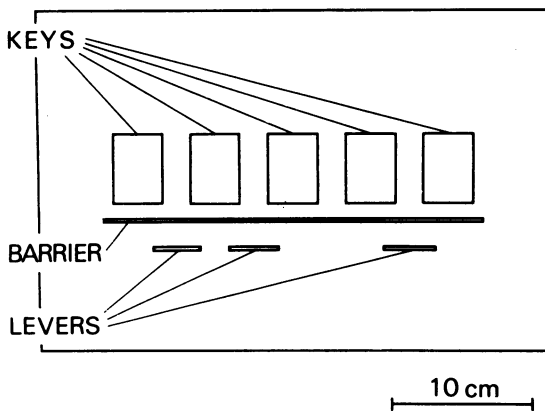


Fig. 1. Front view of the experimental panel attached to one wall of the experimental chamber. (See text for details.)

A minicomputer (Digital Equipment PDP-8/f) controlled the equipment. Data were recorded by the minicomputer and by a cumulative recorder (Gerbrands). Subjects' behavior was monitored by a TV camera.

In this experiment, two keys (Key 4 and Key 5) were used as discriminanda, and one lever (Lever 3) was used for responding.

Procedure

Baseline training. After responses to Lever 3 were shaped, two sessions were conducted with a variable-interval (VI) 1-sec schedule for the lever-pressing responses. The baseline discrimination training was begun on the next day.

Each trial started with the presentation of two stimuli, red or purple on Keys 4 and 5. Responses to Lever 3 were reinforced according to a VI schedule when the two colors were identical (positive trials: red-red and purple-purple), but responses were extinguished when the colors were different (negative trials: red-purple and purple-red). In the initial two sessions, the VI value was 5 sec and positive trials ended with a reinforcer. In the third session and thereafter, the VI value was 20 sec and positive trials ended with a reinforcer or a lapse of 20 sec, whichever came earlier. A reinforcement-buzzer sound of 1 sec and 2-sec illumination of the feeder tray accompanied the reinforcer. Negative trials basically continued for 20 sec. But, as the rate of responding in negative trials did not decrease to a low level, a quasi-DRO (differential-reinforcement-of-other-behavior) 20-sec contingency was introduced for three monkeys (in the ninth session for O393, thirteenth for K371, and fifteenth for T320). In this condition, negative trials lasted until the subjects paused for 20 sec. All stimuli on the keys turned off when the trial ended. Intertrial intervals were 3 sec. Responses to the lever during the intertrial interval period reset the timer. Each session consisted of 60 reinforcers.

The accuracy score of performance was calculated with the following formula: $R_p / (R_p + R_n) \times 100$, where R_p was the rate of responding in the positive trials and R_n was the rate of responding in the negative trials. In the quasi-DRO condition, R_n was calculated as the rate of responding during the initial 20 sec of each negative trial. The training continued

until the accuracy scores exceeded 90 in two successive sessions.

Transfer test. After criterion was reached, the quasi-DRO contingency in the negative trials was removed. The VI value was gradually lengthened to 60 sec, and the number of reinforcers per session was decreased to 30. The transfer test was conducted after the above criterion was satisfied once again.

The test session consisted of 96 trials, half of which were baseline trials and half of which were test trials. In the test trials, only two new colors (blue and bluegreen for T373 and K371, and yellow and yellowgreen for O393 and T320) appeared. These trials were randomly presented, except that the initial four trials of the session were baseline trials. All responses were extinguished after two reinforcers in the initial four baseline trials. Each trial lasted 20 sec.

One monkey (K371) received an additional transfer test. After three recovery sessions (the same as the baseline sessions preceding the transfer test), he was trained with three colors (adding blue to red and purple) under a VI 60-sec schedule. After the criterion described above was reached, his transfer performances to yellow and yellowgreen were tested. This test session consisted of 108 trials. The initial 12 trials were baseline trials. Test trials in which only two new colors were presented and baseline trials randomly appeared with the same frequency in the remaining 96 trials. After three reinforcers in the initial 12 baseline trials, all responses were extinguished. The length of each trial was 20 sec.

RESULTS AND DISCUSSION

The four monkeys acquired the baseline discrimination in varying numbers of sessions—T373: 7; O393: 13; K371: 15; and T320: 37 (criterion sessions excluded).

Figure 2 shows the results of the first transfer test for all monkeys. The vertical axis is the rate of responding per minute for each configuration of stimuli. Each stimulus configuration is shown on the horizontal axis. White bars designate the absolute rate of responding in positive trials, and black bars designate negative trials. Accuracy scores of baseline trials and test trials are shown in each graph.

Baseline performances were not impaired under the extinction condition. One subject

(K371) showed a very low rate of responding for all configurations of test stimuli, but the other three monkeys responded with higher rates on both of the two positive test trials than on any of the negative test trials. The accuracy scores for test trials were nearly 70, which indicated that the rate of responding under positive test stimuli was about twice as high as that under negative test stimuli. The successful transfer obtained to two new colors suggests that some Japanese monkeys are able to form the sameness-difference concept from as few as two stimuli, which generalizes, at least, in regard to color.

As indicated in the *Procedure* section, K371 was trained with three colors after this test session. During this training, the mean accuracy scores for all configurations exceeded 90 in the third session. But, as the rate of responding was not low in two types of negative trials (blue-purple and purple-blue), training was continued with the quasi-DRO contingency introduced in negative trials. The second transfer test was carried out after 13 training sessions.

The results of this second test of K371 are shown in Figure 3. The baseline performance was perfect. In contrast with the first transfer test, clear transfer to two new colors was obtained. Thus, three colors seem to be sufficient for Japanese monkeys to form a sameness-difference concept.

The amount of transfer obtained in the present transfer tests was not great, but it should be considered that transfer responses were never reinforced. The reinforcement of correct responses in test sessions may give rise to rapid learning. In fact, Subject K371, who showed no transfer to blue in the first transfer test (Figure 2), exhibited an accuracy score of 77.2 on trials including blue in his first three-color training session. One must be cautious in concluding the existence of transfer when differential reinforcement is maintained in the test sessions. The present results, because they were obtained without differential reinforcement, are strong evidence for transfer.

The present experiment confirmed that the previous failure to show transfer in matching-to-sample procedures was due to some procedural defects. Then what facilitated concept formation? A careful investigation into the procedural differences between matching to sample and the present procedure reveals two

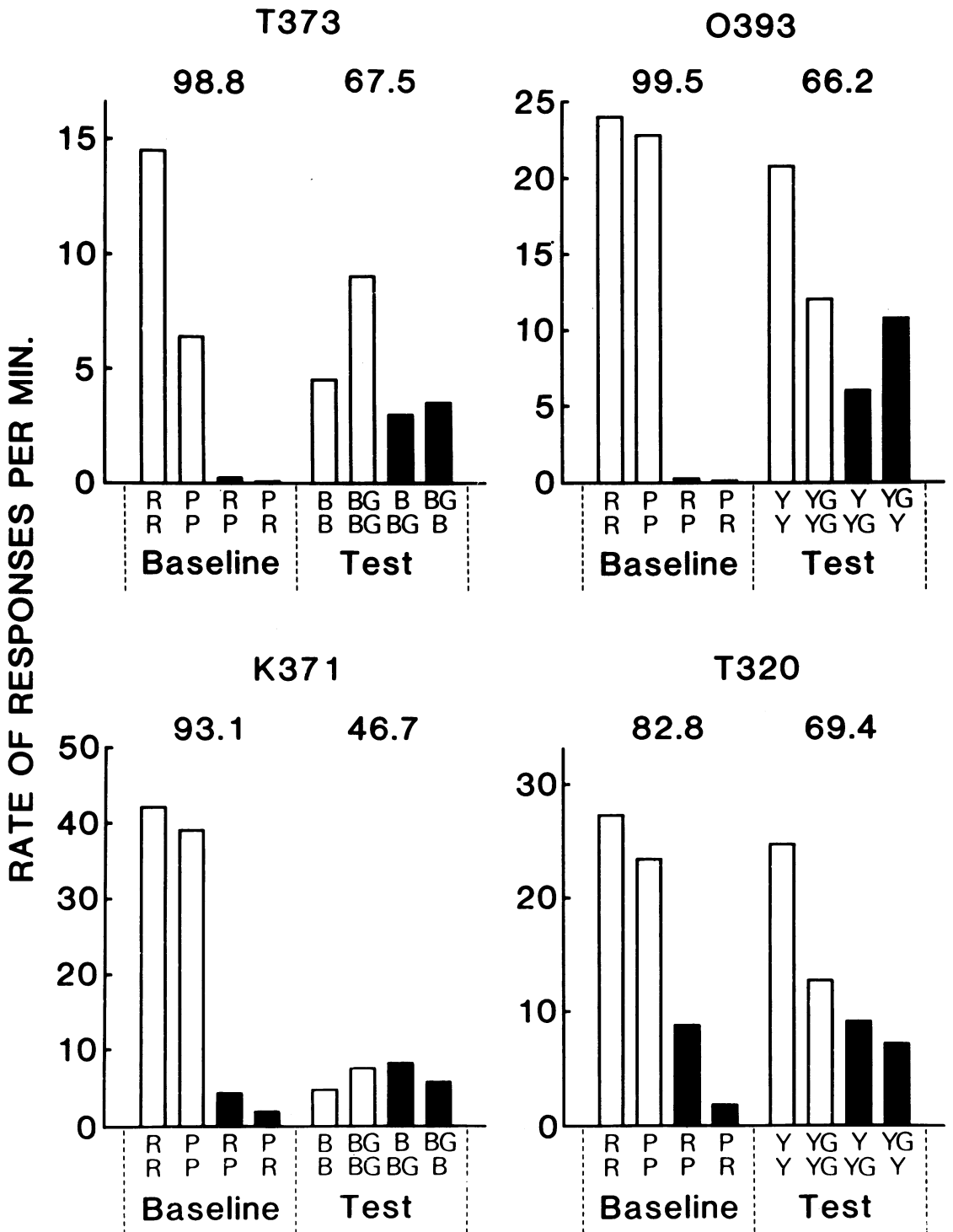


Fig. 2. The results of the transfer test of Experiment 1 (from red and purple to either blue and bluegreen or yellow and yellowgreen, each of which is abbreviated: R, P, B, BG, Y, and YG.). The vertical axis designates the rate of responding per minute for each configuration of stimuli. Note that the gradations differ among subjects. White bars denote positive trials, and black bars denote negative trials. The accuracy scores (see text) in baseline trials and in test trials are shown above each graph.

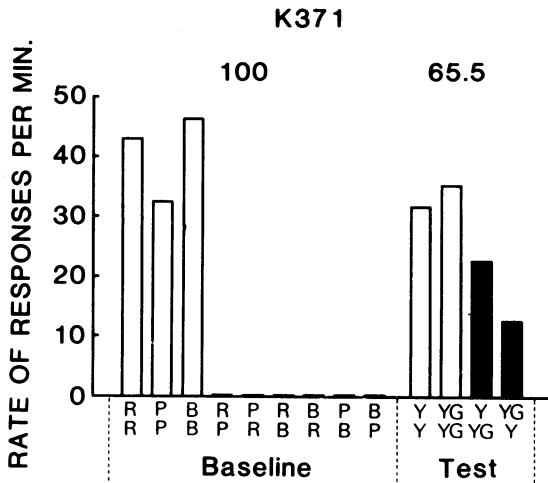


Fig. 3. The results of the second transfer test for K371, who failed to transfer with two-color training, after training with three colors (red, purple, and blue) in Experiment 1. In this test, the subject showed successful transfer to two new colors (yellow and yellow-green). Other details as in Figure 2.

possible factors. One is establishing two independent response patterns to successively presented positive (i.e., matching) and negative (i.e., nonmatching) stimuli. The other is the use of within-trial VI schedules. The following two experiments addressed the question by examining the effect of these two factors on concept formation.

EXPERIMENT 2

Some previous workers (Urcuioli, 1977; Urcuioli & Nevin, 1975; Zentall & Hogan, 1978) have argued that establishing nonresponding to negative stimuli is important in concept formation. They trained pigeons in trialwise Go/No go procedures to refrain from responding to negative stimuli as well as to respond to positive stimuli. The pigeons showed good performances in the following transfer training with new stimuli. This notion may be supported by Malott and Malott (1970), Malott et al. (1971), and Experiment 1 of the present study.

The argument may be generalized as "forming two response patterns is important," because nonresponding is surely a kind of response, which experimenters do not measure as a distinct response. The propriety of such theoretical consideration is supported by Ho-

nig's (1965) study, in which he employed two measurable responses instead of nonresponding. Responses to one key were reinforced with a VI schedule in the presence of two similar hues, and responses to another key were reinforced in the presence of two different hues (a free-operant Yes/No procedure). The discrimination transferred to new hues without reinforcement of the transfer responses.

In sum, two independent response patterns may be of some importance, with little regard for what the response patterns actually are. But, unfortunately, none of the above studies is sufficiently convincing to justify that conclusion. The first three studies with trialwise procedures (Urcuioli, 1977; Urcuioli & Nevin, 1975; Zentall & Hogan, 1978) continued reinforcing pigeons' transfer responses, which might have favored the results to show transfer in some unknown degree. The other four studies (Honig, 1965; Malott & Malott, 1970; Malott et al., 1971; Experiment 1 of this study) employed VI reinforcement, which may have had some facilitating effect on concept formation.

The following experiment attempted to examine the independent effect of establishing two response patterns. A Yes/No procedure was used, because the procedure gives two measurable response patterns and also provides a measure (the proportion of two responses) comparable with that in Experiment 1. Three colors, which Experiment 1 suggested as the sufficient condition for concept formation by all four monkeys, were used for training.

METHOD

Subjects

Two male Japanese monkeys, T271 (7 years old) and M532 (6 years old) served. Both subjects had been trained with three colors on a simultaneous discrimination of a pair of matching stimuli and a pair of nonmatching stimuli just before this experiment. Body weights of the subjects were maintained at approximately 95% of their free-feeding weights.

Apparatus

The apparatus was the same as in Experiment 1. In this experiment, three keys (Key 3, Key 4, and Key 5) and two levers (Lever 2 and Lever 3) were used.

Procedure

Baseline training. After the necessary response sequence was shaped, the discrimination training started. A white dot (10 mm in diameter) was presented on Key 3 at the start of a trial. After three responses to the key (self-start responses), Key 4 and Key 5 were simultaneously lighted as red, purple, or blue. When the two colors matched ("same" trials: red-red, purple-purple, and blue-blue), pressing Lever 3 ("Yes" response) was a correct response, and pressing Lever 2 ("No" response) was an incorrect response. When the two colors did not match ("different" trials: red-purple, purple-red, red-blue, blue-red, purple-blue, and blue-purple), a "No" response was correct and a "Yes" response was incorrect. Either a "Yes" or "No" response turned off all stimuli on the keys. Initially, food was delivered on every correct trial (continuous reinforcement: CRF), accompanied by 1-sec reinforcement-buzzer sound and 2-sec illumination of the feeder tray. Later, food was delivered according to variable-ratio (VR) schedules adopted across trials. Every correct trial increased the VR counter by one. Under the VR condition, the reinforcement buzzer sounded for .5 sec on each correct trial that did not satisfy the VR. Incorrect trials were followed by a 5-sec timeout accompanied by a timeout-buzzer sound of 1 sec. The houselight was turned off during the timeout periods. Inter-trial intervals were .5 sec. Any response during the inter-trial intervals and the timeout periods reset the timer.

The "same" trials and the "different" trials were randomly presented with the same frequency. Each session ended with 80 reinforcers. A correction procedure (i.e., the same trial was repeated after incorrect responses until a correct response was made) was used for only a few sessions (3rd through 5th sessions for T271 and 3rd through 6th sessions for M532). Both subjects were trained until the percentage of correct responses exceeded 90 for two successive sessions.

Transfer test. After reaching the criterion, both subjects were overtrained by the following procedure. As T271 reached the criterion with the CRF schedule, the VR value was gradually increased to four. M532 met the criterion with the VR 4 schedule, and the

value was increased to 6. Then, noneffective trials (Fujita, 1982) were introduced, in which inter-trial intervals immediately followed the Yes/No response. Correct responses in the noneffective trials did not increase the VR counter. The number of noneffective trials was gradually increased, and the VR value was accordingly lowered to keep the rate of reinforcement unchanged. Finally, half of the trials were noneffective, and the VR value was two for T271 and three for M532. The following tests were conducted after the above criterion was again satisfied and, in addition, the percentage of correct responses for each configuration of stimuli averaged more than 80 for the two sessions.

Half of each test session consisted of baseline trials, one quarter noneffective baseline trials, and one quarter noneffective test trials. Three kinds of "same" test trials and six kinds of "different" test trials were constructed from three new colors—bluegreen, yellowgreen, and yellow—as was done for the three baseline colors. The same test trials and the different test trials randomly appeared with the same frequency. Tests were conducted for three sessions with a limit of 80 reinforcers per session.

RESULTS AND DISCUSSION

The baseline training was completed in seven sessions by T271, and in 18 sessions by M532 (with criterion sessions excluded). The number of sessions for overtraining before testing was 16 for T271 and 19 for M532. The results of the transfer tests are shown in Figure 4. The vertical axis designates the percentage of correct responses, and the horizontal axis designates each test session. Unfilled symbols are the baseline trials and filled symbols are the test trials in which only new stimuli appeared.

Both subjects showed accurate performances for baseline trials throughout the test period. But their accuracy for transfer trials was very low compared with that obtained in Experiment 1. The results rejected the hypothesis that the establishment of two different response patterns was important.

Then what accounts for the previous success obtained in trialwise Go/No go procedures of Urcuioli (1977), Urcuioli and Nevin (1975), and Zentall and Hogan (1978)? A possible explanation: In Go/No go procedures, it may be

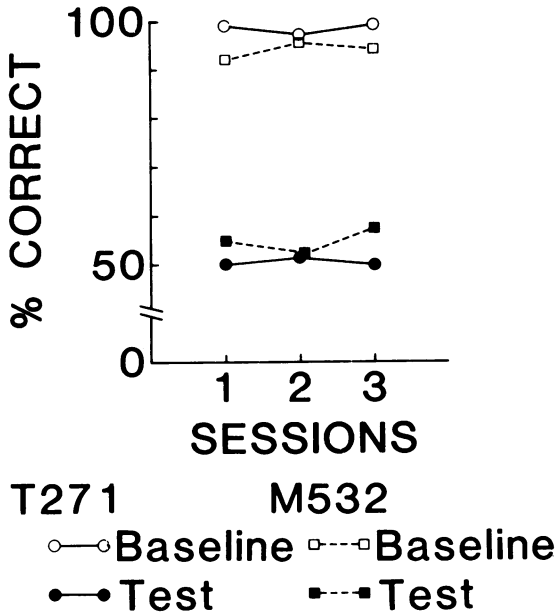


Fig. 4. The results of the transfer test in Experiment 2 (from red, purple, and blue, to bluegreen, yellowgreen, and yellow). The percentages of correct responses are shown in the vertical axis. The horizontal axis designates each test session. Unfilled symbols denote baseline trials and filled symbols denote test trials.

easier for subjects to differentiate the two kinds of responses than in Yes/No procedures, because Yes responses and No responses are topographically similar. Such an advantage may have facilitated transfer of the baseline discrimination, and reinforcement of the animals' transfer responses might have magnified the advantage.

Comparing Honig's success with the present failure, we see the importance of the within-trial VI schedule. The successful transfer obtained without reinforcement in the Malott studies and in Experiment 1 of the present study may have been mainly due to this factor. Experiment 3 examined the effect of this factor on concept formation.

EXPERIMENT 3

No previous workers have focused their attention on the effect of within-trial VI schedules on concept formation. The following experiment examined the potential importance of this factor without the formation of two independent response patterns. The amount of transfer between a standard matching-to-

sample procedure and a modified procedure adopting a within-trial VI schedule was compared, with a within-subject design.

METHOD

Subjects

Three 3-year-old Japanese monkeys, T441 (male), T442 (female), and T446 (male) served. All subjects had some laboratory experience, but they had not experienced any discrimination task that incorporated sameness-difference judgment. Body weights of the subjects were kept at approximately 95% of their free-feeding weights.

Apparatus

The apparatus was the same as in Experiment 1. In this experiment, only Lever 1 and Keys 2, 3, and 4 were used.

Procedure

Baseline matching-to-sample (MTS) training. After the necessary response chain was shaped, baseline training was started. Each trial began with lighting Lever 1. Three responses to the lever (self-start responses) turned off the lever light and produced a sample stimulus on Key 3. After five responses to the sample (observing responses), a comparison stimuli appeared on each side key (Key 2 and Key 4) while the sample remained. One matched the sample and the other did not. A response to the matching comparison stimulus was a correct response, and a response to the non-matching comparison stimulus was an incorrect response. The response to either side key turned off all stimuli on the keys. Initially, food was delivered on every correct trial (CRF), but later, it was delivered according to across-trial VR schedules. Incorrect trials were followed by a 5-sec timeout. Intertrial intervals were .5 sec. All possible configurations of three colors (red, purple, and blue, as in Experiment 2) were used for this baseline training. Each session consisted of 80 reinforcers. The correction procedure was used for some sessions (7th through 12th and 16th through 20th sessions for T441 and 7th and 8th sessions for T442 and T446). The training continued until the percentages of correct responses exceeded 90 for two successive sessions.

MTS transfer Test 1. After reaching the criterion, all subjects were overtrained with the following procedure. The value of the VR was

gradually increased to four for all subjects. Then noneffective trials were introduced and gradually increased in number to comprise half of the trials; at the same time, VR value was lowered to two. The following tests were carried out after the above criterion was again satisfied and after the percentages of correct responses for all possible stimulus configurations averaged more than 80 for the two sessions. Half of each test session consisted of baseline trials, one quarter noneffective baseline trials, and one quarter noneffective test trials in which all possible combinations of three new colors (bluegreen, yellowgreen, and yellow) were presented. The VR value was kept at two. Tests were conducted for three sessions with the limit of 80 reinforcers per session.

Baseline training: free-operant matching-to-sample. After the above tests were finished, one baseline MTS session was conducted with a CRF schedule. In the next session, the intertrial interval was lengthened to 5 sec, and both the self-start responses and observing responses to the sample were decreased to two. Free-operant matching-to-sample (FMTS) training began on the next session.

In FMTS trials, the sequence of stimulus presentations was the same as in the MTS trials. A sample appeared after two self-start responses. Two observing responses to the sample produced two comparison stimuli. As long as these three stimuli (a sample and two comparisons) were present, responses to the matching comparison stimulus (correct responses) were intermittently reinforced with a VI schedule, and responses to the nonmatching comparison stimulus (incorrect responses) were extinguished. The trial ended with a reinforcer or a lapse of 20 sec, whichever came earlier.

The VI value was gradually increased from 1 sec to a final length of 60 sec. Whenever an incorrect response occurred, reinforcement of a correct response was delayed for a predetermined duration (error-delay). The length of the error-delay was 5 sec for T441, and 20 sec for T442 and T446. Each session consisted of 40 reinforcers. The training continued until the percentage of correct responses exceeded 90 for two successive sessions, and, in addition, the average for the two criterion sessions was higher than 80 for each configuration of stimuli.

FMTS transfer test. After criterion was reached, a quarter of the trials were replaced by test trials. As in the MTS transfer Test 1, all possible configurations of test stimuli (bluegreen, yellowgreen, and yellow) were randomly presented. All responses, correct or incorrect, were simply extinguished in the test trials. Each test trial lasted for 20 sec. On baseline trials, which comprised three quarters of all the trials, correct responses were reinforced with a VI 45-sec schedule. Other experimental variables were the same as in the preceding baseline session. Tests were conducted for three sessions with a limit of 40 reinforcers or 2 hr, whichever came earlier.

Recovery MTS training. After the FMTS transfer test, all subjects received baseline MTS training again with a CRF schedule. The requirements of the self-start responses and the observing responses remained unchanged at two. Intertrial intervals were again shortened to .5 sec. The VR reinforcement of correct responses and the noneffective trials were introduced as in the initial baseline MTS training. Finally, half of the trials were noneffective and the VR was two.

MTS transfer Test 2. After the criterion adopted for the MTS transfer Test 1 was satisfied, the same transfer test as in Test 1 was carried out for three sessions.

RESULTS AND DISCUSSION

The baseline MTS performance was acquired in 28 sessions by T441, 31 sessions by T442, and in 8 sessions by T446 (with criterion sessions excluded). The VR value when the subjects reached the criterion was 2, 4, and 1, respectively. The number of overtraining sessions before the MTS transfer Test 1 was 16 for T441, 13 for T442, and 28 for T446. The number of sessions required to train the subjects to reach the FMTS criterion was 20 for T441, 29 for T442, and 29 for T446. All subjects performed fairly well in their recovery MTS session after the FMTS transfer test. The alteration in the duration of intertrial intervals and in the number of self-start and observing responses had no effect on the accuracy of the subjects' performance.

The results of the three tests are shown in Figure 5. The vertical axis designates the percentage of correct responses, and the horizontal axis designates the session. Unfilled sym-

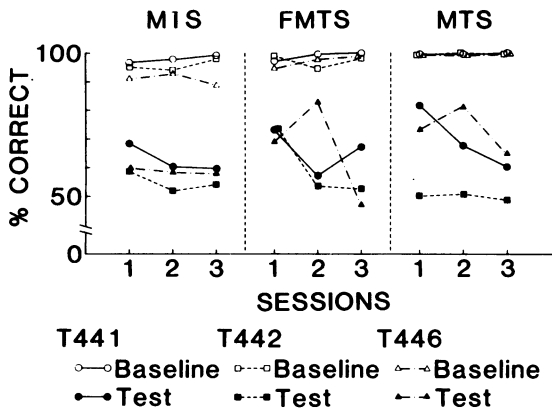


Fig. 5. The results of the three transfer tests in Experiment 3. The percentages of correct responses are shown in the vertical axis. The left panel is the transfer Test 1 of matching to sample (MTS), the center panel is the transfer test of the free-operant matching to sample (FMTS), and the right panel is the transfer Test 2 of the matching to sample. In the baseline FMTS trials, responses to a matching comparison stimulus were reinforced with a variable-interval schedule. Unfilled symbols designate the baseline trials (red, purple, and blue), and filled symbols designate the test trials (bluegreen, yellowgreen, and yellow).

bols are the baseline trials and filled symbols are the test trials.

All subjects showed good baseline performances (unfilled symbols) throughout the test periods. During the sessions of the MTS transfer Test 1 (the left panel), accuracy percentages of the test trials (filled symbols) were no more than 60 except that T441 showed a somewhat successful performance in his first session. This confirms the notion that monkeys barely form a sameness-difference concept in matching-to-sample training with a small number of stimuli.

However, all three subjects showed higher accuracy in the test trials in the first session of the FMTS transfer test (the center panel, filled symbols). The averaged accuracy percentage for the three subjects in the test trials of the first session of the FMTS transfer test significantly increased from that of each session of the MTS transfer Test 1 ($t = 3.48, 4.79, 6.64$, respectively; $df = 2$; $p < .05$). T446 showed an even better performance in the second session. These results suggest that the within-trial VI schedule employed in FMTS training enhanced transfer. In the second or third sessions, the performances of all monkeys deteriorated.

This seems to have been the consequence of repeated presentation of stimuli in which responses were never reinforced. Thus the deterioration is not surprising.

The results of the MTS transfer Test 2 (the right panel) were not consistent among subjects. Two monkeys performed very well in the test trials for two sessions. This result showed that the high transfer accuracy in the FMTS transfer test was not due to the differences of the measure. Poor performances of T442 throughout the test periods may raise questions about this notion, but Figure 5 reveals that repeated presentation of the same stimuli without reinforcement decreases the accuracy on trials presenting those stimuli. Subject T442 may have been very sensitive to the repeated presentation of stimuli without reinforcement. Thus the high transfer accuracy in the FMTS transfer test seems to have reflected the enhanced stimulus control by sameness-difference.

It is possible that overtraining of matching behavior itself might have been effective in strengthening the relational control. Unfortunately, the present experiment cannot directly answer this question. But the effect of the overtraining itself seems to have been small, because after mastery of the baseline MTS task, all subjects received a good amount of overtraining before the MTS transfer Test 1 was conducted. Furthermore, successful transfer was demonstrated not only in this experiment but in all previous experiments that employed within-trial VI schedules (Honig, 1965; Malott & Malott, 1970; Malott et al., 1971; Experiment 1 of this paper). Therefore, one may conclude that the use of a within-trial variable-interval procedure has the effect of strengthening stimulus control by sameness-difference.

GENERAL DISCUSSION

Two major findings were obtained in the present study. Experiment 1 demonstrated that Japanese monkeys are able to form the sameness-difference concept that generalizes at least in regard to color from a minimum number of stimuli (i.e., two). It is probable that other monkey species known to be able to form this relational concept also generalize in similar fashion. Previous work may have

failed to detect such good ability for abstraction simply because of procedural defects.

Experiments 2 and 3 suggest that the important factor that facilitated concept formation was the variable-interval schedule adopted within trials. This raises two questions: First, how general is this finding? Does a VI schedule generally strengthen stimulus control by the general relationship among many kinds of stimuli? If so, this procedure can be applied to many other relational concepts such as larger-than, longer-than, more-numerous-than, and so on. It may be possible to demonstrate the formation of many abstract relational concepts in nonhuman animals. The generality of this finding should be studied further.

The second question is more important: Which aspect of a VI schedule is critical for establishing strong relational control? One possibility is that a simple decrease in the rate of reinforcement might be important for such strong relational control. In Experiment 3, in fact, the rates of reinforcement per minute in the FMTS sessions with a VI 60-sec schedule were between .5 and .7, which were considerably lower than those in the MTS sessions with an across-trial VR-4 schedule (between 3.0 and 3.5). However, a contradictory finding was reported by Ferster (1960). He demonstrated that pigeons' matching-to-sample accuracy decreased when their matching behavior was intermittently reinforced with across-trial interval schedules, in contrast with improving effects of fixed-ratio schedules. Furthermore, Nevin, Cumming, and Berryman (1963) reported that fixed-ratio reinforcement of pigeons' matching behavior decreased matching performance. Thus it is doubtful that a simple decrease in the rate of reinforcement itself strengthens the relational control.

Another hypothesis is possible. At least two training schedules are known to produce flatter generalization gradients after single-stimulus training than VI schedules do. One is the differential-reinforcement-of-low-rates-of-responding (DRL) schedule reported by Hearst, Koresko, and Poppen (1964), and the other is the variable-ratio schedule reported by Thomas and Switalski (1966). Rilling (1977) interpreted these phenomena as the consequence of dual stimulus control: control by previous response (factor A) and control by external stimuli (factor B). He argued that

"when factor A is important, as on DRL and (perhaps) ratio schedules, then factor B is correspondingly less so; hence the flatter gradient" (p. 436). On VI schedules, in which the rate of reinforcement is scarcely affected by the rate and temporal patterns of responding, factor A seems to be unimportant. Therefore the external control is stronger in VI schedules than in DRL or ratio schedules. This advantage of VI schedules found in single-stimulus training ought to work in discrimination situations. In discrimination situations, enhanced external control may make it possible for non-salient aspects of stimuli that do not easily control behavior (such as sameness-difference) to increase their controlling function as a discriminative stimulus. Thus, the potential of VI schedules to enhance external control might be the most critical factor in strengthening the stimulus control by sameness-difference.

Unfortunately, very few relevant studies examining the appropriateness of this hypothesis have been reported. Only Lydersen, Perkins, and Chairez (1977) give information about this problem. They showed that the increase in the fixed-ratio requirement to comparison stimuli (within a trial) lowered the accuracy of pigeons' oddity-from-sample performances. This finding may support the above hypothesis because, as Rilling (1977) suggested, ratio schedules would make the external control weak. But the decrease in accuracy may have been derived from weakened stimulus control by specific association of sample and comparison stimuli, not sameness-difference. Therefore, the work cannot give a clear answer to the question about the appropriateness of this hypothesis.

There are many other aspects that might strengthen the relational control in a VI schedule: for example, a simple increase in the duration of the stimulus presentation, an increase in the number of responses emitted to the stimulus, or random presentation of reinforcement. The effects of these aspects have not been investigated yet in situations relevant to the present study. A more appropriate procedure to study relational concepts in animals can be established if the critical aspect to strengthen stimulus control by the general relationship among stimuli is determined. Further investigations are necessary.

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