AN INVESTIGATION OF THE DIFFERENTIAL-OUTCOMES EFFECT WITHIN SESSIONS

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The differential-outcomes effect is manifest as more accurate performance of a delayed conditional discrimination when alternative choice responses are followed by different reinforcers than when they are followed by the same reinforcer. In Experiment 1, a differential-outcomes effect was demonstrated within sessions by signaling the duration of food access for correct responses with stimuli appearing in conjunction with the sample stimuli. The delayed matching-to-sample performance of 5 pigeons was more accurate when green choice responses (matching a green sample) were followed by 3.5-s food access and red choice responses (matching a red sample) were followed by 0.5-s food access (different-outcome trials) than when the correct choice responses were both followed by 1.5-s reinforcers (same-outcome trials). In Experiment 2, the acquisition of this differential-outcomes effect was characterized by a progressive decrease in rate of forgetting on different-outcome trials and no change in rate of forgetting on same-outcome trials. In addition, accuracy at the shortest delay intervals for both different-outcome and same-outcome trials increased over acquisition, but to a greater extent for different-outcome trials. These data suggest that both memorial and attentional (time-dependent and time-independent) factors contribute to the differential-outcomes effect.

Key words: differential-outcomes effect, delayed matching to sample, initial discriminability, rate of forgetting, key peck, pigeon

The differential-outcomes effect (DOE) refers to more accurate remembering when the outcomes of correct choice responses are different than when the outcomes are the same (Brodigan & Peterson, 1976). The DOE is often observed in discrete-trial delayed conditional discriminations in which the correct choice of either of two comparison stimuli is conditional on the sample stimulus presented earlier in the trial. For example, if red and green are the choice stimuli, delayed matching is more accurate when correct choices of red are followed by a large amount of food and correct choices of green are followed by a small amount of food than when correct choices are followed by the same amount of food. The DOE has been demonstrated with a range of outcomes in delayed conditional discriminations. For example, matching accuracy is higher when the correct choice responses are followed by different probabilities of food presentation

(DeLong & Wasserman, 1981; Santi & Roberts, 1985a, 1985b; Urcioli, 1990a, 1990b), different qualities of food (Brodigan & Peterson, 1976), different locations of a food dispenser (Williams, Butler, & Overmier, 1990), and even food versus no food (Linwick, Overmier, Peterson, & Mertens, 1988; Peterson, Linwick, & Overmier, 1987; Peterson, Wheeler, & Trapold, 1980; Urcioli, 1990b).

In all previous studies, the DOE has been assessed by either between-groups or between-conditions comparisons. For the different-outcome (DO) group or condition, qualitatively or quantitatively different reinforcers follow the two correct responses. In the same-outcome (SO) group or condition, either the same reinforcer follows both correct responses or different reinforcers follow the correct responses equally often. Accordingly, the sample stimuli and choice stimuli in these studies are associated with different reinforcers in the DO groups or conditions but not in the SO groups or conditions.

This feature of the conventional DO paradigm raises two possibilities. First, the discriminability between the choice stimuli in the DO conditions may be enhanced relative to the SO conditions by virtue of their being associated with different reinforcers. That is, more accurate delayed matching in DO conditions may reflect more discriminable choice stimuli

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in these conditions. Second, this feature implies that the sample stimuli in the DO conditions of the prior studies serve dual roles. That is, each sample stimulus signals not only which response is correct at the choice phase but also which of two reinforcers will follow the correct response.

Experiment 1 of the present study examined whether it is critical for the DOE that the sample and choice stimuli are perfectly correlated with the specific reinforcer for each correct response. This issue was addressed by using a within-session procedure. The sample and choice stimuli were the same in two conditional discriminations (DO and SO), and a second stimulus dimension signaled whether different or identical reinforcer durations would follow correct responses. One outcome cue (a triangle) signaled that the same duration of food access (1.5 s) would follow correct matching of red and green sample stimuli. The other outcome cue (a circle) signaled that different durations of food access would follow correct matching of red and green (0.5 s for correct red responses and 3.5 s for correct green responses). Same-outcome and different-outcome trials were mixed within sessions. In this procedure, the DOE would be manifest as more accurate remembering (or more accurate delayed matching) on trials in which different reinforcer durations for the two correct responses were signaled than on trials in which the same reinforcer durations were signaled.

By employing additional stimuli to signal the reinforcers for correct responses, the choice stimuli alone were not predictive of the specific food-access times, because they were both presented on DO and SO trials. Consequently, accuracies on both DO and SO trials should be equally improved if the association of different reinforcers with the two choice stimuli on DO trials enhances the discriminability between these stimuli. In addition, the within-session procedure resulted in an operational separation (albeit partial) of the stimuli signaling which outcome would follow a correct choice response from the stimuli signaling which choice response would be correct. Thus, if either enhanced discriminability between the choice stimuli or the dual role of the sample stimuli were responsible for the DOE, the DOE should not occur in the present procedure.

EXPERIMENT 1

METHOD

Subjects

Five experimentally naive adult homing pigeons (labeled W1 through W5) were maintained at 85% of their free-feeding body weights by supplementary feeding of mixed grain following experimental sessions. Water and grit were freely available in the home cages. Experimental sessions were conducted daily for each bird, provided that its weight was within 15 g of the target 85% weight.

Apparatus

A lightproof sound-attenuating experimental chamber (33 cm wide, 33 cm deep, and 34 cm high) contained an interface panel on one wall and an exhaust fan on the opposing wall. All interior walls were painted matte black. Three horizontally aligned translucent response keys were mounted on the interface panel 24 cm above a wire grid floor. The keys were 2.85 cm in diameter and were set 9.3 cm apart, center to center. The operation of a microswitch mounted behind each key required a minimum force of 0.18 N.

In-line stimulus projectors (IEE with 24-V 1820 lamps) were mounted behind each response key. The projectors contained Kodak® Wratten filters (72B and 74) that could illuminate the rear surface of each key with either red (606 nm peak wavelength) or green (538 nm peak wavelength) colored fields. These stimuli were not equated for brightness. A plain white field and two white outline shapes could also be presented against a colored or a black background on the center key. The shapes were a circle (an annulus) that was 1.8 cm in diameter and an equilateral triangle with 1.6-cm sides.

A hopper opening, 5.5 cm wide and 6.5 cm high, was located directly below the center key and 5.3 cm from the floor. Access to wheat was possible by the operation of a solenoid-operated hopper (Campden Instruments). Hopper presentations were accompanied by the illumination of the aperture by white light and the extinction of all key stimuli. An infrared emitting diode and a phototransistor were mounted opposite each other inside the hopper opening. The infrared beam detected the entrance of the bird's head into the hopper

opening during hopper presentation, and food access was timed from this moment. All experimental events were controlled and recorded by a Digital PDP® 11/23 microcomputer, running SKED-11® software, located in an adjoining room.

Procedure

Preliminary training. Ninety-seven sessions of preliminary training preceded the introduction of the main procedure. This training was conducted in five phases: key-peck shaping, forced-choice training, zero-delay matching-to-sample training, outcome-cue training, and finally, several conditions of delayed-matching training with signaled reinforcers.

All birds were initially trained to peck a white center key by the method of successive approximations. They then received seven sessions in which wheat access followed single responses to either side key when it was illuminated red or green. This was followed by 10 sessions of forced-choice training. Each of 128 trials in this phase began with red or green illumination of the center key. The fifth peck to this key darkened it and immediately lit one of the side keys with the color that matched the center-key color. A response to the lit side key darkened it and produced 3-s access to wheat followed by a 10-s intertrial interval (ITI). A quasi-random order of key colors and side keys was arranged in each session.

During zero-delay matching-to-sample training, the offset of the red or green sample was accompanied by the immediate illumination of both side keys, one red and one green. Red and green were presented on left and right side keys with equal frequency and in a quasi-random order. Responses to the side key that matched the sample were followed by 2-s access to wheat, whereas incorrect responses produced a 3-s blackout. A 10-s ITI then elapsed before the next trial began. This training continued until each bird chose correctly on at least 95% of the trials for five consecutive sessions. This criterion was satisfied after 30 sessions.

In the fourth phase of training, zero-delay matching-to-sample was maintained. However, on half of the trials, different food-access times were introduced for correct red and correct green responses. Different reinforcers on the DO trials were signaled by superimposing

the white circle over the red or green sample stimulus, whereas the same reinforcers on SO trials were signaled by superimposing the white triangle. The fifth response to this compound stimulus extinguished only the sample; the outcome cue remained on the center key when the side keys were illuminated for the choice. When the circle was superimposed on red, a correct choice response produced 1-s access to wheat. When the circle was superimposed on green, a correct choice response produced 4-s access to wheat. When the triangle was superimposed on the sample, correct responses to both red and green produced 2-s access to wheat. Again, all incorrect responses produced 3-s chamber blackout. Each session in this condition consisted of four blocks of 32 trials. In each block, red and green sample stimuli, left and right positions of the correct choice stimulus, and circle and triangle outcome cues (eight unique stimulus combinations) were presented equally often in a quasi-random order. All birds received a minimum of 17 training sessions in this condition.

In the final phase of preliminary training, trials were identical to those described above except that four different delay intervals were interpolated between the offset of the sample and the onset of the choice phase. The four delay intervals were presented quasi-randomly across trials. For the first 10 sessions, delay intervals were 0.01, 0.5, 1, and 2 s. In the next 10 sessions, delay intervals were 0.01, 1, 2, and 4 s, and in the final phase of training, delay intervals were 0.01, 1, 4, and 8 s. On each trial in these 30 sessions, the outcome cue was present during the presentation of the sample stimuli, during the delay interval, and during the choice phase. The presentation of the outcome cues throughout the delay interval and choice phase ensured that there was no delayed stimulus control by these cues.

Main procedure. Food-access times in the experimental condition were reduced to 1.5 s on SO trials and 0.5 and 3.5 s on DO trials. Figure 1 illustrates the sequence of events that defined the four trial types. On each trial, the outcome cue was presented in conjunction with the sample and during the delay interval and choice phase. The fifth response to the sample-outcome-cue stimulus was followed by a delay interval of 0.01, 1, 4, or 8 s. At the choice phase, the two side keys were lit either green

Different-Outcome Trials

Same-Outcome Trials

Fig. 1. Stimulus arrangements and event sequences of the procedure arranged in Experiment 1. On different-outcome trials (signaled by the circle), correct choices of green were followed by 3.5-s access to food and correct choices of red were followed by 0.5-s access to food. On same-outcome trials (signaled by the triangle), both correct green and correct red choices were followed by 1.5-s access to food.

on the left and red on the right or vice versa. On trials in which the outcome cue was the circle (DO trials), correct green responses produced 3.5-s access to wheat, whereas correct red responses produced only 0.5-s access to wheat. On trials in which the outcome cue was the triangle (SO trials), both correct red and correct green responses were followed by the same 1.5-s access to wheat.

Each session in this condition consisted of 128 trials arranged in four blocks of 32 trials. The trials in each block uniquely combined red and green sample stimuli, circle and triangle outcome cues, left and right positions of the correct choice stimulus, and four delay intervals. The quasi-random order of trials was constrained so that each stimulus combination occurred equally often, and so that red or green, circle or triangle, left or right, or any one of the four delay intervals could not occur on more than three consecutive trials. Each of the 32-trial blocks arranged a different sequence of trials. Each bird was trained in this condition until all birds had received at least 30 sessions.

The data collected from each session were the numbers of correct and incorrect responses made to the left and right side keys on each of the four sample-by-outcome trial types (see Figure 1). These data were recorded separately for each of the four delay intervals.

RESULTS AND DISCUSSION

Individual-subject analyses of matching accuracy on SO and DO trials at each delay interval were based on frequencies of choice responses summed over the last 10 sessions of training. Consequently, 160 trials (80 presenting the red sample and 80 presenting the green sample) were considered in the calculation of each estimate of accuracy at each delay interval on DO and SO trials. Figure 2 shows the proportion of trials on which each bird chose the correct comparison stimulus as a function of the duration of the delay interval on SO and DO trials. The group data are the mean proportion-correct responses averaged over individual birds.

Three trends are apparent in Figure 2. First, for all birds, accuracy on both SO and DO trials generally decreased as the delay interval increased. This finding is typical of the forgetting functions in delayed matching-to-sample procedures (Blough, 1959; Roberts, 1972;

White, 1985). Second, Figure 2 illustrates clear evidence of a DOE. That is, for all birds, proportion-correct scores were higher on trials with different reinforcer durations (DO trials) than they were on trials with the same reinforcer durations (SO trials). Out of 20 possible comparisons, there were only two instances in which accuracy on DO trials was not higher than accuracy on SO trials (Birds W2 and W5 at 0.01 s). Thus, the birds generally matched more accurately when differential reinforcers were signaled than when the same reinforcers were signaled, even though these outcome cues were irrelevant cues for choice responding.

Superior matching accuracy on DO trials in the present experiment is consistent with the results of previous studies in which either qualitatively or quantitatively different reinforcers were arranged to follow correct responses in delayed conditional discriminations (Brodigan & Peterson, 1976; Honig, Matheison, & Dodd, 1984; Urcuioli, 1990a, 1990b, 1991). In addition, this result extends a result reported by Carlson and Wielkiewicz (1976), who trained rats in a simultaneous conditional discrimination involving auditory sample stimuli and two response levers. One group, which was presented with a large number of food pellets for one correct response and a small number of pellets for the other, learned the discrimination more rapidly than did other groups that received either the same amount of food for both responses or large and small reinforcers randomly.

By employing additional stimuli to signal the reinforcers available for correct responses (the outcome cues), the same sample and choice stimuli could be presented on DO and SO trials in the present procedure. Consequently, in contrast to earlier studies, neither sample stimulus and neither choice stimulus alone was predictive of a specific reinforcer. The DOE in the present procedure therefore suggests that an enhanced discriminability between the choice stimuli cannot alone account for the DOE. That is, any discriminability change that may have resulted from associating the two choice stimuli with different reinforcers on DO trials in the present study would be expected to generalize to the choice stimuli on SO trials. In addition, the DOE here suggests that the dual role of sample stimuli in previous DO procedures was not critical for the generation of the DOE. In other words, the stimuli

Fig. 2. Proportion correct on different-outcome (DO) trials (filled circles) and same-outcome (SO) trials (unfilled circles) as a function of delay-interval duration in Experiment 1.

signaling the specific reinforcers for correct responses at the choice phase can differ from those signaling which responses will be correct. However, it is important to note that the sample stimuli and outcome cues in the present procedure were not entirely independent. That is, on DO trials, the specific reinforcer was signaled by the conditional relation between the sample and the outcome cue. In any experimental design, the sample stimulus must always be a component of the stimulus signaling the specific reinforcer. Nevertheless, the present experiment has partially decoupled this confounding effect and has demonstrated clear conditional stimulus control of the DOE by the outcome cues.

The third trend apparent in Figure 2 is that the difference between accuracy on DO and SO trials generally increased as the delay interval increased. When the proportion-correct data were submitted to a repeated measures analysis of variance, there was a statistically significant interaction between trial type (SO and DO) and delay interval, $F(3, 12) = 9.66$, $p < .05$. Post hoc analyses indicated that this interaction was due to statistically significant differences between accuracies on SO and DO trials at delay intervals of 1 s, 4 s, and 8 s, but not at 0.01 s.

The interaction between trial type and delay interval observed in the present study indicates that the rate at which accuracy decreased with increasing delay intervals differed for SO and DO trials. This may imply that the rate of forgetting was greater on SO trials than on DO trials. Indeed, this interaction has been reported in several other studies (e.g., Brodigan & Peterson, 1976; Peterson, Wheeler, & Armstrong, 1978; Peterson et al., 1980; Williams et al., 1990) and has often been interpreted as evidence that memorial (time-dependent) processes and not discrimination (time-independent) processes underlie the DOE.

A potential problem with this argument, however, concerns the mathematical properties of proportion correct as a measure of matching accuracy. First, proportion correct has an upper bound at 1.0 (perfect matching) and an effective lower bound at .5 (chance accuracy). These bounds constrain the range of changes in accuracy when proportion correct is near 1.00 or .5, compared to the larger changes that are possible when proportion cor-

rect is around .75. As Nevin and Grosch (1990) note, this may result in comparisons of changes at different accuracy levels being ambiguous and difficult to interpret. A solution to this problem is offered by a logistic transformation of proportion correct, logit p (Nevin & Grosch, 1990). That is,

$$\text{logit } p = \log p(c)/[1 - p(c)], \quad (1)$$

where $p(c)$ refers to proportion correct and the logarithm is to the base 10.

To illustrate the comparison of forgetting functions when accuracy is measured by logit p , Figure 3 shows the group data from the present study as well as from three other studies (Linwick et al., 1988; Peterson et al., 1987; Urcioli, 1990b) when accuracies on SO and DO trials were reanalyzed in terms of logit p . All four studies used very different procedures, but in all cases there are considerable differences between logit p measures at the shortest delay intervals, as well as some differences in the rate of forgetting on SO and DO trials.

EXPERIMENT 2

Experiment 1 identified a procedure in which the DOE can be brought under the control of a conditional stimulus (an outcome cue). The DOE in this procedure was manifest as a difference in the rate at which matching accuracy declined with increasing delay intervals on SO and DO trials, as well as a difference in matching accuracy at the shortest delay interval. The present experiment examined how these two aspects of the DOE developed while subjects were learning the conditional discriminations comprising this task.

In a reanalysis of data reported by Berryman, Cumming, and Nevin (1963), White (1985) found that overall accuracy tends to improve with continued training in standard (SO) delayed matching-to-sample procedures, but rate of forgetting does not change over the course of acquisition (Figure 7). In addition, numerous studies have shown that not only do groups receiving differential reinforcers attain higher asymptotic levels of matching accuracy, but they also acquire stable performance with less training than their SO controls (e.g., Peterson & Trapold, 1982; Peterson et al., 1980). These findings imply that the difference in accuracy at the shortest delay interval in Experiment 1 might be the result of different

Fig. 3. Discriminability estimates (logit p , Equation 1) as a function of delay-interval duration for DO conditions (filled circles) and SO conditions (unfilled circles) calculated for group data from studies reported by Linwick et al. (1988, Figure 3), Peterson et al. (1987, Figure 4), Urcuioli (1990b, Figure 2), and Experiment 1 of the present study.

levels of improvement in accuracy over the course of training for DO and SO trials. Also, a within-session manipulation of outcomes is likely to involve the learning of at least two independent conditional discriminations. One is the standard delayed matching-to-sample task, and the other involves the function of the outcome cues. It is therefore possible that the difference in rate of forgetting between DO and SO trials develops over the course of acquisition, independently of the change in overall accuracy.

The results of a comparison between the acquisition of delayed-matching accuracies on SO and DO trials are likely to have implications for the major theoretical accounts of the DOE. For instance, if differential outcomes simply enhance the discriminability between the sample stimuli (see Edwards, Jagielo, Zentall, & Hogan, 1982), matching on DO trials should be more accurate than on SO trials at all delay intervals. This account of the DOE also predicts that the difference between accuracies on SO and DO trials will be relatively

constant across delay intervals, and that there will be no difference in rates of forgetting on DO and SO trials with continued training. If, on the other hand, lower rates of forgetting on DO trials than on SO trials develop with training, then the resulting DOE may be more easily accommodated by outcome-expectancy theory. Proponents of this theory (Peterson & Trapold, 1980, 1982; Trapold, 1970) argue that superior remembering on DO trials reflects the operation of differential outcome expectancies that mediate the control of choice responding by the samples. These expectancies are presumed to persist longer in time than "memories" of the sample stimuli, so that accuracy on DO trials is less affected by the duration of the delay interval than is accuracy on SO trials.

Experiment 2 examined acquisition of performance in a task that was similar to that arranged in Experiment 1 (see Figure 1). That is, SO and DO trials were mixed and cued within sessions, and matching accuracy was assessed at four delay intervals. The course of acquisition was analyzed by comparing delay-interval functions for successive blocks of 10 sessions.

METHOD

Subjects

Five adult homing pigeons (labeled C1 through C5) were maintained at 85% of their free-feeding body weights by supplementary feeding of mixed grain following experimental sessions. Four of the birds (C1, C2, C3, and C5) had prior experience with a conditional discrimination task involving moving shapes as the sample stimuli. Bird C4 had no prior experimental experience. Water and grit were freely available in the home cages. Experimental sessions were conducted daily for each bird, provided its weight was within 15 g of the target 85% weight.

Apparatus

A lightproof sound-attenuating experimental chamber (different from that used in Experiment 1; 33 cm wide, 33 cm deep, and 34 cm high) contained an interface panel and an exhaust fan. Three horizontally aligned translucent response keys were mounted on the interface panel 25.6 cm above a wire grid floor. The keys were 2.85 cm in diameter and were set 9.15 cm apart, center to center. A minimum

force of 0.15 N operated a microswitch mounted behind each key.

The two side keys could be illuminated red or green by lamps situated behind them. An in-line stimulus projector (IEE with 24-V 1820 lamps) was mounted behind the center response key. This projector contained Kodak® Wratten filters (72B and 74) that could illuminate the rear surface of the key with either red (606 nm peak wavelength) or green (538 nm peak wavelength) colored fields. These stimuli were not equated for brightness. A white horizontal line or a white vertical line could also be presented on the center key against either the colored background of the sample stimulus or a black background. Each line was 0.92 cm wide and covered the diameter of the key. Effective responses to the center key when it was illuminated by either sample were followed by a 50-ms offset of the key stimulus.

A hopper opening (5.5 cm wide by 6.5 cm high) was located directly below the center key and 5.3 cm from the floor. A solenoid-operated hopper (Campden Instruments) delivered wheat through this opening. Presentations of the hopper were accompanied by white-light illumination of the aperture and the extinguishing of all key stimuli. An infrared emitting diode and a phototransistor were mounted opposite each other inside the hopper opening. The infrared beam detected the entrance of the bird's head into the hopper opening during hopper presentation, and food access was timed from this moment. All experimental events were controlled and recorded by an 80386 microcomputer running MED-PC® software in an adjoining room.

Procedure

Seventeen sessions of preliminary training preceded the introduction of the main procedure. Following magazine training, all birds were trained to peck a white (unfiltered) stimulus on the center response key by the method of successive approximations. Responding to this stimulus was subsequently reinforced according to a variety of reinforcement schedules (continuous, fixed-ratio, and variable-ratio reinforcement). This training continued for seven sessions. The birds were then trained to peck each of the three response keys when they were illuminated red or green (one at a time). In these discrete trials, 3-s access to food followed the fifth response to whichever stimulus was

present. Successive stimulus presentations were separated by a 10-s ITI, during which time the chamber was dark. Two quasi-random series determined the order in which red or green illuminated one of the three keys. The same color or response key was not presented on more than three consecutive trials, and each of the six possible trial types (combining color and response-key position) was presented five times in each session. This training continued for 10 sessions, by which time each bird was reliably responding to each stimulus on each response key.

The main procedure was introduced immediately after preliminary training. The sequence of events defining the experimental trials were identical to those arranged in Experiment 1 (see Figure 1). The present procedure differed in only two ways. A vertical line and a horizontal line replaced the annulus and triangle as the DO and SO cues, and only 96 trials were presented per session. Each trial began with the presentation of the red or green sample stimulus and the vertical or horizontal line on the center key. Following five responses to this key, the sample stimulus was extinguished (the outcome cues remained) and a delay interval of 0.01 s, 1 s, 4 s, or 8 s was initiated. The delay interval terminated with the presentation of red and green choice stimuli on the two side keys. On trials in which the outcome cue was the vertical line, correct responses to the green choice stimulus produced 3.5-s access to wheat, whereas correct red responses produced only 0.5-s access to wheat. On trials in which the outcome cue was the horizontal line, both correct red and correct green responses were followed by the same 1.5-s access to wheat. All incorrect responses produced 3-s chamber blackout, and trials were separated by a 10-s ITI.

Each session consisted of 96 trials arranged in three blocks of 32 trials. The trials in each block uniquely combined red and green sample stimuli, vertical and horizontal outcome cues, left and right positions of the correct choice stimulus, and four delay intervals. The quasi-random order of trials was constrained so that each stimulus combination occurred equally often, and so that red or green, vertical or horizontal, left or right, or any one of the four delay intervals could not appear on more than three consecutive trials. Each bird was trained

with this procedure until all birds had received at least 80 sessions.

The data collected from each session were the numbers of correct and incorrect responses that a bird made to the left and right side keys on each of the four sample-by-outcome trial types. These data were recorded separately for each of the four delay intervals. In addition, the number of responses made to any of the three keys during the delay interval on each of the four sample-by-outcome trial types was recorded.

RESULTS AND DISCUSSION

The acquisition of correct matching in the present experiment was examined by summing response frequencies across successive 10-session blocks of training. The differences between accuracy on SO and DO trials was assessed by comparisons within blocks, and changes in accuracy on both trial types were assessed by comparisons across blocks. In each of the analyses described below, the data from only 3 birds are reported. The excluded birds (C1 and C2) consistently completed only about 66% of the trials scheduled in a session and therefore contributed data that reflected an unequal number of trials of the different types.

Acquisition of accuracy on SO and DO trials at each delay interval was initially assessed in terms of proportion-correct scores. Figure 4 shows proportion correct on SO and DO trials at each delay interval for each block of 10 sessions over the first 60 sessions of training. The final 20 sessions of training (Days 61 through 80) were collapsed into one block.

Figure 4 shows two trends in the acquisition of delayed matching on SO and DO trials. First, for all birds overall accuracy on both trial types at each delay interval increased with training. During the first 10 sessions of training (Days 1 through 10), proportion correct on SO and DO trials was approximately .5. In other words, delayed-matching accuracy was initially at chance level. However, over the next 40 days (Days 11 through 50), proportion correct on both trial types generally improved. By Days 51 to 60, accuracy on DO trials had increased to a level between .89 and 1.0, and accuracy on SO trials ranged from .61 to .98. A comparison of accuracies over Days 51 to 60 and Days 61 to 80 suggests that perfor-

Fig. 4. Proportion correct on DO trials (filled circles) and SO trials (unfilled circles) for Birds C3, C4, and C5 as a function of delay-interval duration for six successive blocks of 10 sessions and a final block of 20 sessions in Experiment 2.

mance on both trial types at each delay interval was stable after 60 days of training.

The second trend in Figure 4 concerns the development of the DOE. Specifically, the difference between proportion correct on SO and DO trials generally increased with training. That is, superior accuracy on DO trials was not immediately apparent, but emerged gradually and at a rate comparable to the improvement in overall accuracies. Furthermore, this trend was more pronounced at the longer delay intervals.

Figure 4 shows that for each bird, the delay-interval functions during Days 61 to 80 were very similar to those in the final stage of training in Experiment 1 (Figure 2). That is, proportion correct decreased as the delay interval lengthened, accuracy on DO trials was higher overall than accuracy on SO trials, and the difference between accuracy on SO and DO trials increased as the delay interval increased. However, unlike Experiment 1, birds in the present experiment were seldom perfectly accurate on either red- or green-sample SO or DO trials. The occurrence of errors permitted an analysis in terms of bias-free and un-

bounded measures of discrimination accuracy. The measure of discrimination accuracy used was the point estimate of stimulus discriminability ($\log d$) from the model of signal-detection performance proposed by Davison and Tustin (1978) and by Nevin (1981) and applied to delayed matching to sample by White and McKenzie (1982). This measure of discriminability is the same as d_e from Luce's (1963) choice theory and has similar properties to d' (Green & Swets, 1966). $\log d_t$ ($\log d$ at delay-interval t) is calculated as the logarithm (base 10) of the geometric mean of the ratios of correct to incorrect responses on red- and green-sample trials. That is,

$$\log d_t = 0.5 \cdot \log[(P_{rc} \cdot P_{gc}) / (P_{re} \cdot P_{ge})], \quad (2)$$

where P_{rc} and P_{re} refer to the number of correct and incorrect responses on red-sample trials, respectively, and P_{gc} and P_{ge} refer to the number of correct and incorrect responses on green-sample trials, respectively.

Figure 5 shows estimates of $\log d_t$ on SO and DO trials as a function of delay-interval duration for each block of sessions. Because the performance of individual birds was con-

Fig. 5. Estimates of sample-stimulus discriminability, $\log d_i$, (Equation 2) as a function of delay-interval duration on DO trials (filled circles) and SO trials (unfilled circles) over successive blocks of 10 sessions in Experiment 2. These estimates were based on response frequencies pooled over Birds C3, C4, and C5. The smooth curves are the best fitting negative exponential functions given by Equation 3. The associated parameter values ($\log d_0$ and b) and proportion of variance accounted for (VAC) are shown above each pair of functions.

sistently similar (Figure 4), the estimates of $\log d_i$ plotted in Figure 5 were calculated from response frequencies pooled across the 3 birds. Several of the trends apparent for proportion correct (Figure 4) also appear in Figure 5. For example, estimates of $\log d_i$ on both SO and DO trials generally increased over the first 60 sessions of training, whereas across blocks of Days 51 to 60, 61 to 70, and 71 to 80, estimates of $\log d_i$ on both trial types showed no systematic changes. Figure 5 also shows that up until the fifth block of sessions (Days 41 to 50), the difference between $\log d_i$ estimates on SO and DO trials systematically increased with training, so that the magnitude of the DOE at each delay interval increased.

The gradual emergence of the DOE as overall matching accuracy improved (Figure 5) may be interpreted in at least three ways. First, the gradual divergence of accuracy on DO and SO trials may be evidence of subjects learning two conditional discriminations in a hierarchical fashion. That is, it may be that subjects required some degree of mastery of the sample-correct choice discrimination (the matching-to-sample conditional discriminations) before they learned the associations between the sample-outcome-cue compound stimulus and the specific reinforcer durations. Second, it could be that subjects simultaneously learned separate delayed-matching conditional discriminations on SO and DO trials, and that the

Table 1

Estimates of initial discriminability ($\log d_0$) and rate of forgetting (b) for different- and same-outcome trials for Birds C3, C4, and C5, for Days 51 through 80. Also shown are the proportion of variance accounted for (VAC) and the mean squared error term (MSE) for each best fitting exponential function.

Bird	Different-outcome trials				Same-outcome trials			
	$\log d_0$	b	VAC	MSE	$\log d_0$	b	VAC	MSE
C3	1.919	0.057	.88	0.010	1.509	0.128	.98	0.003
C4	1.315	0.125	.93	0.008	1.155	0.360	.95	0.008
C5	2.239	0.081	.89	0.022	1.592	0.193	1.0	0.001

gradual emergence of the DOE reflected different rates of acquisition on these trials. Third, this gradual emergence may reflect the independent development of control by the matching-to-sample and the outcome-cue conditional discriminations in which control by the latter develops later or at a slower rate than control by the former. In other words, it may simply reflect the development of stimulus control by the outcome cues. Although this latter argument is clearly the most parsimonious, the present data do not permit an evaluation of these interpretations. This issue may be clarified by a further experiment in which the associations between specific reinforcer durations and a sample-outcome-cue compound are trained prior to the introduction of the delayed matching-to-sample task.

White and McKenzie (1982; see also White, 1985, 1991) suggested that the effect of increasing delay intervals was to degrade sample-stimulus discriminability according to a negative exponential function of time. That is,

$$\log d_t = \log d_0 \cdot \exp(-bt), \quad (3)$$

where $\log d_t$ is the discriminability between the sample stimuli at time t since their presentation, $\log d_0$ is the discriminability between the stimuli when $t = 0$, and b is a constant that describes the rate at which the discriminability between the sample stimuli decreases with time t . In other words, $\log d_0$ measures initial discriminability, and b measures the rate of forgetting.

Equation 3 was fitted to estimates of $\log d_t$ as a function of delay-interval duration using nonlinear least squares regression. In Figure 5, parameter values for the best fitting exponential functions (Equation 3) and the proportion of variance accounted for by each regression are shown above each set of data. This analysis was conducted for each block of ses-

sions except Days 1 to 10. During this block, $\log d_t$ values on both SO and DO trials were very close to zero (chance performance). Consequently, estimates of $\log d_0$ converged to zero, and estimates of b were undefined.

With only one exception (DO trials over Days 71 to 80), the forgetting functions in Figure 5 were described well by Equation 3. The proportion of variance accounted for by each regression (VAC) ranged from .74 to 1.0, with a mean of .95 and a median of .96. The mean squared error terms (MSE) ranged from 0 to 0.022, with a mean of 0.005 and a median of 0.005. There was, however, one noticeable trend in measures of goodness of fits; in all blocks of sessions except Days 71 to 80, Equation 2 accounted for more variance in the functions for DO trials than for SO trials.

Two results are clear from comparisons of the two parameters within each block of sessions. For each block, estimates of $\log d_0$ were higher and estimates of b were lower for DO functions than for SO functions. In other words, during each block, signaling differential reinforcers increased the initial discriminability between the sample stimuli ($\log d_0$) and decreased the rate at which the sample stimuli were forgotten (b). Both of these differences were also evident in the data for individual birds. Estimates of $\log d_0$ and b for each of the 3 birds were obtained by fitting Equation 4 to estimates of $\log d_t$ calculated from the final 30 sessions of training (Days 51 to 80). By summing response frequencies across these 30 sessions, the same number of trials that contributed to estimates of $\log d_t$ for the group (Figure 5) also contributed to the calculation of $\log d_t$ estimates for individual birds. Table 1 presents values of $\log d_0$ and b for the best fitting functions as well as the proportion of variance accounted for by each function and the mean squared error terms. For each bird, estimates

Fig. 6. Estimates of the initial discriminability between the samples ($\log d_0$, top panel) and rate of forgetting (b , lower panel) on DO trials (filled circles) and SO trials (unfilled circles) derived from negative exponential functions (Equation 3) that best described the data for successive blocks of 10 sessions in Experiment 2.

of $\log d_0$ were higher for DO functions than for SO functions. Estimates of b were also lower for DO functions than for SO functions.

Figure 5 also shows that there were systematic changes in estimates of $\log d_0$ and b across blocks of sessions. These changes have been summarized in Figure 6, which shows values of $\log d_0$ and b for SO and DO delay-interval functions plotted as a function of blocks of training sessions. Note that no estimates of b are provided for the delay-interval functions for Days 1 to 10 because this parameter was undefined in this block of sessions. Figure 6 shows systematic changes in the difference between both $\log d_0$ and b on SO and DO trials as a function of training. First, $\log d_0$ values for both SO and DO delay-interval functions increased with training, and reached an asymptote by Days 51 to 60. Second, the differ-

Fig. 7. Estimates of the initial discriminability between the samples ($\logit p_0$, top panel) and rate of forgetting (b , lower panel) derived from negative exponential functions (Equation 3) that best described the acquisition data reported for Bird 171 by Berryman et al. (1963).

ence between the estimates of $\log d_0$ for SO and DO functions was not constant across blocks, but increased as training proceeded.

The bottom panel of Figure 6 shows that values of b for DO functions were lower overall than for SO functions, and that this difference increased with training. The increasing difference between b values resulted from a steady decrease in b for DO functions and no reliable change in b for SO functions. In other words, rate of forgetting (b) decreased on DO trials with continued training, but remained relatively constant for SO trials.

An increase in $\log d_0$ but no change in b values on SO trials (Figure 6) is consistent with reanalyses of acquisition data for the standard delayed matching-to-sample procedure. White (1985) reanalyzed acquisition data reported by Berryman et al. (1963). Figure 7 shows the results for Bird 171 in the study reported by Berryman et al., reanalyzed in terms of Equations 1 and 3. Over five successive blocks of 12 sessions, $\logit p_0$ (an estimate of the discriminability between the stimuli when $t = 0$) systematically increased, whereas

the corresponding estimates of b remained relatively stable (see also McCarthy & White, 1987). Whereas the lack of change in b for SO trials over the course of acquisition in Experiment 2 is consistent with acquisition in the standard (same-outcome) delayed matching-to-sample procedure, the reduction in b over acquisition for DO trials suggests that the DOE is uniquely characterized by a lowered rate of forgetting on DO trials. Moreover, this decrease in b on DO trials implies that some "learning to remember" took place on these trials.

This "learning to remember" on DO trials may well reflect the development of stimulus control by the outcome cues. However, a further explanation for this effect is implied in an account of the DOE referred to as peripheral-response-mediation theory (Trapold & Overmier, 1972). This theory differs from outcome-expectancy theory (Peterson & Trapold, 1980, 1982; Trapold, 1970) by offering sample-specific behavior, rather than some centrally represented "reinforcer expectancy," as the event(s) that mediate sample-stimulus control of choice responding. According to this theory, the associations between sample stimuli and reinforcers in a DO procedure promote the development of unique overt chains of responding following each sample stimulus. Insofar as matching is more accurate in a DO procedure, the proprioceptive or interoceptive stimuli arising from sample-specific responses on these trials are presumed to provide either additional cues for correct choice responding or more salient cues that replace control by the sample stimuli (Brodigan & Peterson, 1976; Peterson & Trapold, 1980). Indeed, all birds in the present experiment consistently pecked the response keys during the delay interval. Thus, it may be that the decrease in rates of forgetting (b) with training on DO trials reflected the development of sample-specific responding during the delay interval on these trials and the development of stimulus control by these kinds of sample-specific behavior.

To investigate this possibility, we analyzed the rate at which birds pecked any of the three keys during the delay interval on each of the four sample-by-outcome trial types. Figure 8 shows the mean number of responses per second made by Birds C3, C4, and C5 during the delay interval on red- and green-sample DO and SO trials in each successive block of five

Fig. 8. The mean number of responses per second that Birds C3, C4, and C5 made during the delay interval on red- and green-sample DO and SO trials in each successive block of five sessions.

sessions. Although response rates during the delay interval were higher overall on DO trials than on SO trials, Figure 8 shows only limited evidence for the development of sample-specific rates of responding on DO trials. Bird C4 developed more pronounced sample-specific rates of responding on DO trials than on SO trials, and for Bird C3 there was a consistently greater difference in response rates on DO trials than on SO trials, although the difference was small. Therefore, the possibility that the decrease in rate of forgetting with training on DO trials reflected the development of sample-specific rates of responding that were serving a mnemonic function receives only weak circumstantial support. It is of course possible

that some other aspect of behavior during the delay interval on DO trials was sample specific, exerted control over choice responding, and developed at a rate comparable to the decrease in rate of forgetting. For example, given that we did not record which key was pecked on the various trial types, delay-interval responding on DO trials may have been sample specific with respect to response location. Although such possibilities are difficult to rule out, several authors have argued that a distinction between peripheral-response-mediation theory and outcome-expectancy theory is not worthwhile because the cognitive/behavioral controversy over the nature of expectancies is an intractable dilemma. Peterson (1984) for example, argued that whether reinforcer expectancies are represented in the central nervous system or as observable peripheral responses is a moot point and is not critical for outcome-expectancy theory. However, if this means that outcome-expectancy theory is not directly testable, the explanation for the facilitation of matching accuracy by delay-interval mediating behavior should rest at the level of observable (and measurable) behavior.

GENERAL DISCUSSION

The present experiments demonstrated and investigated the differential-outcomes effect in a delayed matching-to-sample task in which the reinforcers for correct choice responding were manipulated within sessions. By signaling the reinforcers for correct responses with cues that were separate from the sample stimuli and irrelevant with respect to choice responding, the present experiments extended the range of conditions that support the DOE. They demonstrated that any enhanced discriminability between the choice stimuli on DO trials in prior studies of the DOE, and the dual role of sample stimuli in these studies, is likely to have contributed little, if anything, to the facilitative effect of DOs.

In Experiment 2, differences between delay-interval functions for SO and DO trials were described in terms of the two parameters, $\log d_0$ and b , of the best fitting negative exponential functions (Figure 5). These parameters are said to be influenced by two sets of variables (White, 1991). First, time-independent or "attentional" factors determine the initial dis-

criminability between the sample stimuli ($\log d_0$). These are the factors that affect matching accuracy in a simultaneous conditional discrimination in which there is no short-term remembering requirement. Second, time-dependent or "memorial" factors include conditions during the delay interval and choice phase; these determine rate of forgetting or the rate at which sample-stimulus discriminability decreases with increasing delay intervals (b).

The question of whether time-independent or time-dependent factors produce the DOE is theoretically important, because each of these factors is implied in the two most popular accounts of the DOE: the "acquired distinctiveness of cues" notion (Peterson & Trapold, 1980) and outcome-expectancy theory (Trapold, 1970). According to the acquired distinctiveness of cues, the DOE reflects the operation of time-independent or attentional factors that affect the overall discriminability between the sample stimuli. That is, by associating different reinforcers with the two sample stimuli, each will be remembered more accurately (delayed-matching accuracy will be higher) because the discriminability between them has been enhanced by adding another stimulus dimension (e.g., food-access duration) to each. In terms of Equation 2, such enhanced discriminability should be evident as higher $\log d_0$ values on DO trials than on SO trials but no systematic differences in b .

Outcome-expectancy theory (Trapold, 1970), on the other hand, invokes time-dependent or memorial factors and can more readily accommodate differences in rates of forgetting on SO and DO trials (i.e., a difference in b values on SO and DO trials). This theory asserts that associating different reinforcers with each sample permits the sample stimuli to elicit differential expectancies of these reinforcers (via a Pavlovian process). These differential expectancies are claimed to decrease the rate of forgetting by persisting longer than memories of the sample stimuli through the delay interval, and by supplementing sample memories in the control of choice responding.

In Experiment 2, both initial discriminability and rate of forgetting differed between SO and DO trials. In all but the first block of training, DO functions were characterized by higher estimates of initial discriminability ($\log d_0$) and lower estimates of rate of forgetting

(b) than were SO functions. The results of the present study therefore suggest that the DOE involves both time-independent and time-dependent factors and that both explanations described above may indeed be viable accounts. This possibility is favored by the fact that neither explanation posits theoretical constructs that truly discount the other. At a more empirical level, associating different reinforcers with the two correct choice responses may invoke time-independent and time-dependent factors in the following way. First, DOs may improve overall delayed-matching accuracy by enhancing the discriminability between the sample stimuli via the mechanism(s) offered in accounts of the acquired distinctiveness of cues phenomenon (see Edwards et al., 1982; Peterson & Trapold, 1982). Second, DOs may attenuate the effect of increasing delay intervals on matching accuracy and thus decrease rates of forgetting by promoting sample-specific behavior that alters delay-interval and choice-phase conditions on these trials. Outcome-expectancy theory (Trapold, 1970) and peripheral-response-mediation theory (Trapold & Overmier, 1972) offer similar mechanisms by which this might occur.

Further, in view of empirical evidence for the independence of estimates of initial discriminability and rate of forgetting (White, 1991), separate processes may underlie these two components of the DOE. The possible contributions of two independent processes must be clarified by further research. Nevertheless, various alternatives seem to be forthcoming from the success of the present within-session procedure. For example, varying the temporal location of the outcome cue on each trial could demonstrate the relative influence of time-independent and time-dependent factors and permit an assessment of their independence. The aim of such an experiment would be to replicate parameter invariance by investigating whether eliminating or changing one component of the DOE systematically affected the other component. For instance, relative to a baseline condition in which the outcome cue is present throughout the entire trial, delaying the presentation of the outcome cues until the delay interval may reduce or eliminate the difference between estimates of $\log d_0$ on DO and SO trials but not affect the difference between estimates of b .

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