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EFFECT OF DELAY-INTERVAL ILLUMINATION ON MATCHING BEHAVIOR IN THE CAPUCHIN MONKEY[1]

M. R. D'AMATO AND WARD O'NEILL

RUTGERS UNIVERSITY

Experiment 1 demonstrated that delayed matching-to-sample in the capuchin monkey was superior when the delay interval was spent in darkness rather than in moderate illumination. In contrast with previous studies in which the delayed-matching ability of primates appeared limited to 60 sec or less, in the dark condition all subjects showed above-chance matching at a 120-sec delay interval. Experiment 2 verified that darkness during the delay interval can facilitate delayed matching and provided evidence that the effective variable was the illumination level of the delay interval rather than change in illumination, which in Exp. 1 was confounded with illumination level.

The use of matching tasks in behavioral analysis has, as pointed out by Weinstein (1941), a long history, dating back at least to the work of Itard in the early nineteenth century with the "Wild Boy of Aveyon". Much of the work done with matching paradigms has involved simultaneous matching, in which the sample, or more generally, the standard stimulus occurs simultaneously with the comparison stimuli. In delayed matching-to-sample, a period of delay intervenes between the removal of the sample and appearance of the comparison stimuli. The delayed matching-to-sample (DMTS) paradigm appears to lend itself well to the investigation of retention processes on the animal level. It is more flexible and potentially allows for better experimental control than the delayed-response paradigm (Hunter, 1913), which for so long was used for investigating animal memory (*cf.* Fletcher, 1965).

As yet, however, relatively little is known concerning the variables that control performance in delayed-matching tasks. One potentially important variable is the lighting condition that prevails during the delay (retention) interval. Etkin (1970) tested three capuchin monkeys at various delay intervals ranging from 1 to 24 sec, varying the delay-interval ambient illumination between near-total darkness and a moderate level provided by a 15-w overhead houselight. He uniformly found superior performance in the dark condition. The major purpose of the present research was to determine whether this result extends to retention intervals considerably greater than 24 sec.

Previous investigators have found the delayed-matching performance of primates to be rather limited (*e.g.,* Jarrard and Moise, 1970; Scheckel, 1965). For example, the stumptail monkeys of the Jarrard and Moise study, although well practiced in delayed matching, performed very poorly at delay intervals of only 30 sec. Rather than representing structural limits of short-term memory, such results may be indicative of less than optimal experimental conditions. Possibly the matching performance of primates can be extended significantly by manipulation of the delay-interval illumination.

EXPERIMENT 1

In this study, the effect of delay-interval illumination on matching behavior was assessed at retention intervals of 16, 60, and 120 sec.

METHOD

Subjects

The three subjects, Pete, Basil, and Roscoe, all adult male capuchin monkeys (*Cebus apella*), had served in earlier studies of delayed matching (Etkin, 1970; Etkin and D'Amato, 1969). During the present experiment, they were maintained at 85 to 95% of their full-ration body weight.

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Apparatus

Two Lehigh Valley monkey chambers (Model 1317) were modified by adding five inline stimulus projectors (Industrial Electronic Engineers, Inc., Series 10,000) arranged in the pattern ⁙ . Each projector was fitted with a transparent plastic key, which served as the response mechanism. To be recorded as a choice response, a key press had to be maintained for a minimum of 0.4 sec. A microswitch, with which the subject initiated a trial, was centered below the five projectors. CIBA banana pellets (190 mg) served as reinforcers and were delivered to a small cup located on the right wall 4.5 in. (11 cm) from the stimulus panel.

Presentation of stimuli was arranged by a block tape reader described previously (D'Amato, 1965). As projected, all forms were composed of 17-mm white lines approximately 1.5 mm thick on black backgrounds. The four stimuli used were a square, a triangle, a vertical line, and a red field that illuminated a circular area approximately 1 in. (2.5 cm) in diameter. The subjects' behavior was closely monitored over closed-circuit television.

Procedure

A typical DMTS trial proceeded as follows. After completing 15 responses (FR 15) on the microswitch, one of the four stimuli (the sample) appeared on the center projector and remained there until the subject pressed the center key for a minimum duration of 0.3 sec. The sample then disappeared and the delay interval began. At the termination of the latter, two comparison stimuli (the sample and one of the other three stimuli) appeared on two of the four outer projectors. The comparison stimuli remained present until the subject responded to one of them. Each correct response was followed by delivery of one food pellet, after which the subject could initiate the next trial (by completing the FR 15 on the microswitch). Incorrect responses were followed by a 1-min timeout, signalled by the dimming of the overhead houselight. At the end of the timeout, the subject could initiate the next trial.

The lighting condition during the delay interval was manipulated as follows. In the houselight-on condition, the houselight remained illuminated throughout the trial sequence; the only change in ambient illumination occurred during a timeout, when the houselight was dimmed by adding a 500-ohm resistor in series with the 15-w bulb. The maximum illumination on the floor of the experimental chamber measured 6 ft.c. in the houselight-on condition and 1 ft.c. during a timeout period.

In the houselight-off condition, as soon as the subject responded to the sample, thus initiating the delay interval, the houselight was extinguished (producing near-total darkness) and remained off throughout the delay interval. At the termination of the latter, the houselight was illuminated simultaneously with the presentation of the two comparison stimuli.

In the first phase of the experiment, which began approximately three weeks after the termination of Etkin's (1970) studies, a total of 12 sessions were given with a 16-sec delay interval, six in the houselight-on condition and six in the dark condition, intermixed in a quasi-random fashion. During the next phase, the retention interval was increased to 60 sec and six sessions were administered, three each in the houselight-on and houselight-off conditions, which alternated daily. Finally, the delay interval was increased to 120 sec, and the two houselight conditions alternated daily for a total of eight sessions. All sessions were comprised of 40 trials, and each subject received all of the conditions described in the order given.

The stimuli were equated with respect to the number of times each served as sample and as comparison stimulus, and the stimuli were paired with each other with equal frequency. In addition, each of the four projectors was assigned to present the correct and incorrect comparison stimuli equally often.

Results

The accuracy functions for each subject in the houselight-on and houselight-off conditions are shown in Fig. 1. It is apparent that matching performance was superior when the delay interval was spent in darkness. Individual *t* tests, based on an arc sine transformation of the percentage of correct responses achieved in each daily session, were performed for each subject. Of the nine *t* tests that compared performance in the houselight-on and off conditions at the 16-, 60-, and 120-sec delay intervals, only two failed to reach conventional significance levels (Pete at 16- and 120-sec delay); all others were significant at better than the 0.01 level.

In order to assess the degree to which the facilitating effect of the houselight condition varied with the stimuli used as samples, the percentage errors committed on each sample was calculated separately for the houselight-on and off conditions over the combined 16-, 60-, and 120-sec delay intervals. Each sample was presented for a total of 130 trials in each of the two conditions, but because of occasional printer failures, about 7% of the data were unrecoverable. Table 1 presents for each subject and each sample the decline in error rate that occurred in the houselight-off condition. (If a subject had an error rate of 30% for a sample in the houselight-on condition and 20% in the dark condition, the reduction in error rate is 33%.) All of the entries in the table are positive, indicating that performance was uniformly higher in the houselight-off condition. There is a considerable difference in the degree to which each subject's performance was affected by the houselight-off condition; however, within-subject variability across samples is much less marked.

The maximum delay interval at which each subject maintained statistically significant matching behavior was determined by t tests comparing percentage of correct responses obtained at each houselight and delay-interval condition against the assumed chance baseline of 50%. The performance of all three subjects exceeded chance expectation ($p < 0.02$ or less) at all points except in the houselight-on condition at 120-sec delay ($p > 0.10$ or greater).

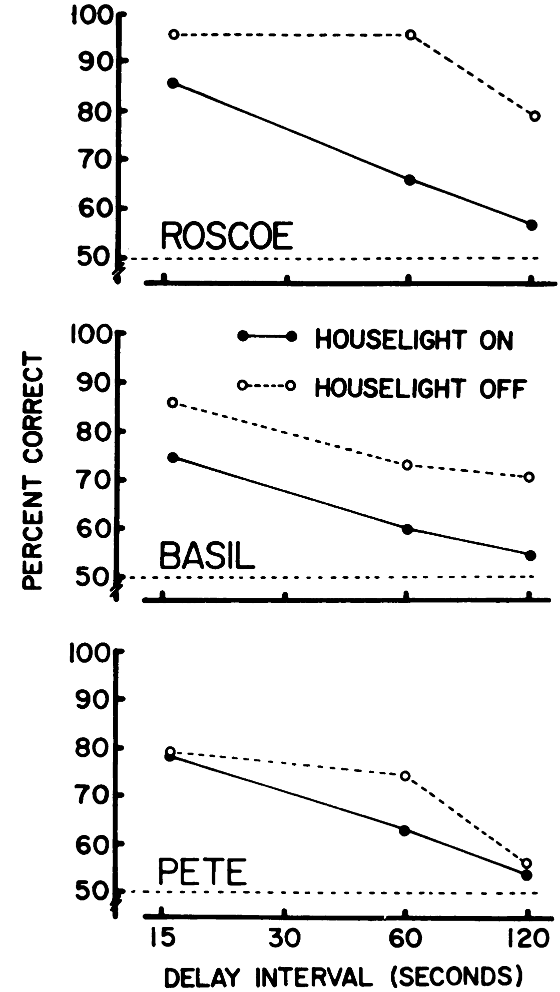

Fig. 1. Delayed-matching performance of the three subjects of Exp. 1 as a function of duration and lighting condition of the delay (retention) interval.

Discussion

It is evident from the present results that the delayed-matching capacity of subhuman primates far exceeds the 30 to 60 sec obtained in previous experiments. Moreover, recent data collected in our laboratory establish that the capuchin monkey is capable of successful matching at delays of at least 4 min. Possibly, previous investigators (*e.g.*, Jarrard and Moise, 1970; Scheckel, 1965) would have obtained results more consonant with ours had the delay interval been spent in darkness, although a definite conclusion on this score is precluded by the many differences in experimental procedures. In this connection, both Jarrard and Moise (1970) and Scheckel (1965) manipulated the delay interval by means of a titration technique in which the delay interval automatically increased or decreased in accordance with the subject's performance level. One po-

Table 1

Per cent reduction in error rate in houselight-off condition in Exp. 1.

	Sample				
Subject	*Red Field*	*Square*	*Vertical Line*	*Triangle*	*Mean %*
Roscoe	53.2	61.5	66.7	74.5	64.0
Basil	18.9	50.5	45.1	20.5	33.8
Pete	7.5	13.1	5.8	20.7	11.8
Mean %	26.5	41.7	39.2	38.6	36.5

tential danger of this technique is that the subject may engage in behavior (failing to attend to the sample or failing to make a response) that serves effectively to avoid the longer delay intervals. Where one is interested in the delayed-matching capacity of animals, the titration technique may yield misleading results unless controls, such as scheduling probe trials of long delays, are instituted.

EXPERIMENT 2

Though our manipulations of delay-interval illumination have led to consistent results, the facilitation shown by the houselight-off condition might simply be due to the fact that in this condition the illumination of the experimental chamber changes during the delay interval rather than being attributable to the direction of change. In the houselight-on condition, illumination was present during the sample display period, the delay interval, and at the time that the comparison stimuli were presented. In the houselight-off condition, on the other hand, the delay interval was spent in darkness. To establish that delay-interval darkness rather than mere change in illumination was the important factor, one must arrange to have delay-interval darkness occur under conditions where it does not represent an illumination change. This was accomplished in the present experiment by modifying the houselight-off condition so that the houselight was extinguished during the sample presentation period, the delay interval, and during the period when the comparison stimuli were presented. In the houselight-on condition, on the other hand, the chamber was illuminated during the delay interval but not during presentation of the sample and comparison stimuli. Thus, in this experiment the ambient level of illumination was increased during the delay interval rather than decreased.

METHOD

Subjects and Apparatus

The two subjects, adult female *Cebus apella,* had a variety of experimental experience, including DMTS. Throughout the experiment they were maintained at 85 to 95% of their full-ration weight. The apparatus and stimulus materials were the same as those employed in Exp. 1.

Procedure

Twenty-four trials were given in each session. The subjects were trained on simultaneous matching for three or four sessions. They were then shifted to 0-sec delay, and as they met the criterion of 88% correct responses in a single session, the duration of the delay interval was increased gradually until a point was reached where they failed to display rapid improvement in performance. In order to assess properly the independent variable of the study, a delay interval had to be chosen that generated matching performance that was above chance, but not so high as to introduce a "ceiling effect". This turned out to be 24 sec for Coco and 50 sec for Fifi. The sequence of events on a typical trial was comparable to that of Exp. 1, except for chamber lighting conditions. As in Exp. 1, the houselight was on during the intertrial period (the period separating completion of one trial and initiation of the next); however, it was off for the sample display period, the delay interval, and during presentation of the comparison stimuli.

Directly after acquisition training was completed, the effect of illumination during the delay interval was evaluated by presenting each subject with four cycles of the houselight-on and houselight-off conditions. The houselight-off condition was merely a continuation of the lighting conditions of acquisition. The only difference in the houselight-on condition was that the houselight was turned on during the delay interval. Two sessions (of 24 trials) were given in the houselight-on condition followed by two sessions in the off condition, the four sessions representing a "cycle". Four such cycles were given to each subject.

Correct responses were reinforced with one 190-mg CIBA pellet. Incorrect responses were followed by a 1-min timeout, during which the houselight was dimmed.

RESULTS

Acquisition

The acquisition data presented in Fig. 2 show that both subjects achieved criterion on successively increasing delay intervals rather rapidly, until the final delay duration was reached. Neither subject had experienced delay intervals greater than 24 sec in prior experiments, a delay duration at which Coco performed very poorly (*cf.* Etkin, 1970).

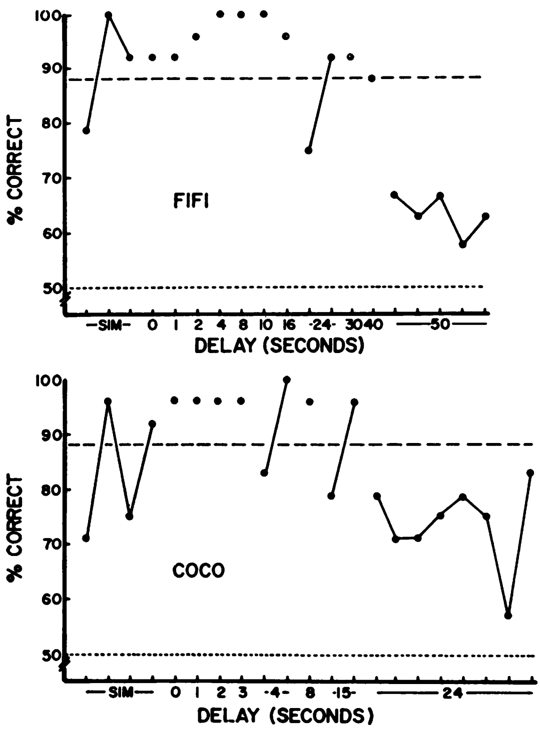

Fig. 2. Delayed-matching performance during the acquisition phase of Exp. 2, which began with simultaneous (SIM) matching. The delay interval was increased in the order shown on the abscissa as the subjects achieved the criterion of 88% correct responses in a session of 24 trials. The connected points signify that more than one session was given at the same delay.

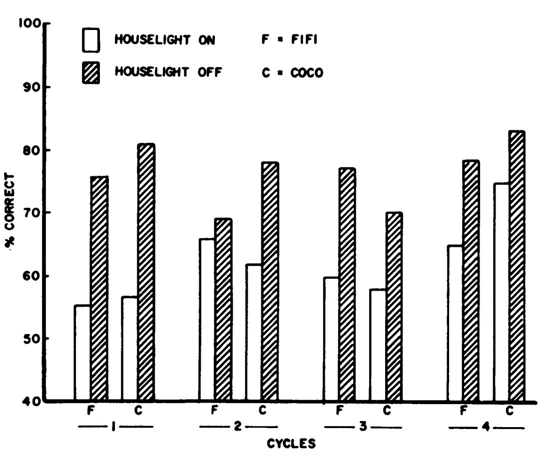

Fig. 3. Delayed-matching performance in the four cycles of houselight-on and houselight-off conditions of Exp. 2. Each bar represents the average performance over two sessions. The delay interval was 50 sec for Fifi and 24 sec for Coco.

Figure 3 presents the results from the four cycles of the houselight-on and off conditions. It is clear that once again darkness during the delay interval facilitated delayed-matching. Individual *t* tests based on the percentage of correct responses attained in a daily session showed both subjects to perform at a significantly higher level in the houselight-off condition ($p < 0.05$ for Coco and $p < 0.01$ for Fifi).

Table 2 presents the percentage reduction in error rate that occurred in the houselight-off condition. Because of printer failure, approximately 5% of the data were not available for this analysis. Note that the mean percentage of reduction in error rate across the two subjects is rather close to the corresponding mean obtained in Exp. 1 (Table 1). However, the distribution of error-rate reduction across the four samples is somewhat different in the present experiment. The greatest divergence occurs with respect to the triangle, which apparently was unaffected by the lighting condition of the delay interval. (For this sample, the difference in performance between the two lighting conditions was not statistically significant for either subject.)

Table 2

Per cent reduction in error rate in houselight-off condition in Exp. 2.

Subject	*Sample* Red Field	Square	Vertical Line	Triangle	Mean %
Fifi	60.1	31.9	54.6	−16.4	32.6
Coco	47.5	27.7	74.3	−16.4	33.3
Mean %	53.8	29.8	64.5	−16.4	33.0

Discussion

Apart from confirming the facilitation of matching behavior by delay-interval darkness, the present results indicate that reduction in delay-interval illumination is responsible for such facilitation rather than change in illumination *per se*. As for the basis of the effectiveness of the delay-interval illumination variable, several possibilities exist. By reducing ambient illumination to a very low level immediately after sample presentation, it is conceivable that after-images are preserved that aid as cues for subsequent matching responses. A somewhat related hypothesis is that delay-interval darkness allows more effective consolidation of the sample "memory trace" than does the illumination that is present during the houselight-on condition. However, both of these possibilities are contraindicated by an experiment of Etkin (1970) in which illumination probes of varying duration were inserted at either the beginning or the end of a delay interval. For example, in an otherwise dark 18-sec delay interval, a 2-sec light probe (houselight-on) was presented either during the first two or the last two seconds of the retention interval. If preservation of after-images or enhanced consolidation were important factors in the facilitation shown by delay-interval darkness, the light probe inserted at the beginning of the delay interval ought to prove more deleterious than the light probe that occurred at the end of the retention interval. Etkin's results did not support this expectation. Instead, his subjects performed slightly better when the probe appeared at the beginning of the delay interval. The duration of the light probe inserted into the delay interval was the effective variable, rather than the location of the probe. Further speculation as to the basis of the effectiveness of the lighting variable should probably await additional experimental results. For example, it would be of value to know if delay-interval darkness facilitates delayed matching in modalities other than vision (*e.g.*, audition), and whether manipulations of ambient noise levels affect delayed matching in visual tasks.

Finally, it should be pointed out that although there have been a number of experiments in which delay-interval illumination was manipulated in a delayed-response task, the results obtained in this situation have been inconsistent (*cf.* Hornbuckle, 1969; King and Clawson, 1966; King, Flaningam, and Rees, 1968; Malmo, 1942; McDowell and Brown, 1960). In the delayed-response paradigm, the subject is required to remember a spatial location rather than the nature of a visual stimulus. The potential for facilitation of performance that illumination provides in this type of task must be taken into account. More specifically, illumination during the delay interval may provide cues by means of which the animal can maintain bodily orientation toward the correct alternative (spatial location) and thereby bridge the delay interval. Quite possibly, the facilitation arising from this source may often be sufficient to outweigh any deleterious effect of illumination on retention. Indeed, were an animal to depend entirely upon such orientation, there would be little need to resort to memory processes to account for accurate delayed-response performance. In our delayed-matching situation, because of the use of multiple response keys and sample sets composed of more than two members, the likelihood of an animal bridging the delay interval by bodily orientation or other overt mediating behavior is remote; moreover, close observation (in the houselight-on condition) over closed-circuit television has never revealed such behavior. It is perhaps for this reason that the facilitating role of delay-interval darkness comes through unambiguously in our studies.

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