

## DELAYED MATCHING IN THE PIGEON

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A discriminative stimulus is sometimes said to "control" the strength or probability of a response. How long does such control last after the stimulus disappears? How is control maintained in the absence of the stimulus? What variables affect this control? Hunter (1913) introduced the study of these problems in his classic experiments on the delayed response in animals and children. The present paper reports the behavior of pigeons in an operant delayed matching situation. Pigeons matched a flickering or steady sample by pecking the correspondingly illuminated response key. This matching behavior was found to depend on the length of the delay intervening between the disappearance of the sample and the bird's choice response, and upon the bird's behavior during the delay interval.

### METHOD

#### *Subjects and Apparatus*

The subjects were four young male pigeons (Palmetto White Carneaux). The birds were maintained at a level of food deprivation at which they behaved effectively, three at about 80% of free-feeding weight, one (bird 1) at 70%.

The birds worked in an experimental box equipped with two 1-inch translucent plastic response keys, spaced 2.25 inches horizontally between centers. Between the keys was the "sample," a vertical aperture approximately 0.3 by 1.6 inches, backed by translucent plastic. Six-watt bulbs illuminated the keys and sample independently, with white light, either flickering (about 10 cycles per second) or steady, or with a red light. A 6-watt "house light" illuminated the box at all times. A solenoid-operated feeding tray below the response keys presented grain reinforcement. Food was available for only about 2.3 seconds at each reinforcement, just enough time for the bird to pick up a grain or two. An automatic switching circuit programmed the presentation of stimulus lights and food reinforcements. Pecks were recorded on a bank of counters and an Esterline-Angus multiple event recorder.

### PROCEDURE

Following magazine training, the birds were trained by approximation to peck both response keys. Then, the following sequence of stimuli was introduced. First, the sample was illuminated for 1 second by white light, either flickering or steady. When this stimulus disappeared, the two keys, previously dark, were illuminated. One of the keys, left or right at random, was illuminated by a steady light, the other by a flickering light.<sup>2</sup> These lights stayed on until the bird pecked either key. The bird received reinforcement every time it "matched" the sample, that is, when it pecked the flickering key following the flickering sample, or the steady key follow-

<sup>1</sup>This research was carried out while the author was on the staff of the Laboratory of Psychology, National Institute of Mental Health. The author wishes to thank Mr. William H. Jones for his assistance.

<sup>2</sup>Flickering and steady lights, rather than colored lights, were used to reduce the possibility of a delayed response based on colored after-images.

ing the steady sample. If the bird "mismatched," it received no food. In either case, a 5-second "intertrial" period intervened during which the keys were illuminated by red light ( $S^A$ ). This sequence is the same as that shown in Fig. 1, except that the delay (step 2) was not yet employed. On each trial following a "match," a new sample

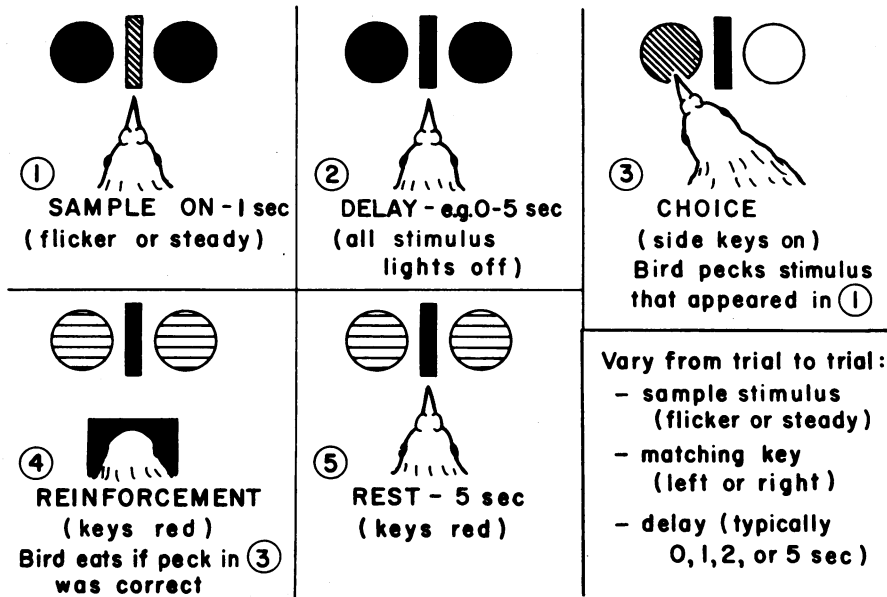


Figure 1. The sequence of events in a single delayed matching trial.

and key-light sequence appeared after the  $S^A$ , as determined by a randomized program that repeated after each 20 presentations. Following the  $S^A$  after a "mismatch," the sample and keys were illuminated in the same pattern as before. The bird received the same stimulus sequence over and over again until it pecked the correct key. However, only the bird's first response to any sequence was counted in determining its percentage of correct responses; that is, responses on the "correction" trials did not enter into the computation of results.

Following the initial sessions in which the choice of keys was made immediately following the presentation of the sample, delays were introduced into the matching situation (step 2 of Fig. 1). The delays intervened between the disappearance of the sample and the appearance of the key lights. The duration of the delays presented during any one experimental session varied according to a randomized program over four values, always including as one value the "0" or no-delay condition.

The birds continued to receive food for each correct peck. Pecks that occurred when the response keys were not lighted, or were red, were ineffective, except that a peck on either key during the delay period produced the red  $S^A$  on the response keys, followed, 5 seconds later, by a repetition of the sample.

Each session continued until the bird had responded correctly 100 times after each of the four delay durations, for a total of 400 reinforcements. Reinforcements

were so brief that the birds usually ate no more than their standard daily ration during the session. The sessions lasted on the average about 2 hours. The birds were observed at intervals through a plexiglas window in the top of the experimental box, and any striking behavior patterns were noted. Birds 5 and 1 were not observed during the first 20 sessions.

PROCEDURE AND RESULTS FOR INDIVIDUAL BIRDS

*Bird 5*

After an initial two sessions with zero delay, Bird 5 received a series of delays that increased rapidly in average duration. After the sixth session the bird worked on a schedule including delays of 0, 2, 5, and 10 seconds. Within 20 sessions the bird was matching correctly more than 90% of the time at all delays. This performance improved slightly over the remainder of the first 50 sessions. The mean performance over Sessions 43 to 50 is shown in Fig. 2, uppermost curve.

Visual observations during these sessions revealed that during the delay interval the bird was performing stereotyped behavior similar to the "superstitious" behavior described by Skinner (1948). Figure 2 (inset) illustrates this behavior, which consisted of two repetitive chains of quite different topography. When the sample flickered, the bird backed quickly away from the keys and waved its head slowly back and forth throughout the delay interval. Following a steady sample, the bird spent the delay pecking rapidly at the top of the vertical sample bar. Sometimes, Bird 5 did not maintain its head-waving response following a flickering sample through a long delay, but began pecking at the sample bar. When this happened, the bird almost always pecked the steady (incorrect) stimulus when the key lights appeared. Thus, these responses in the delay interval seemed to mediate the discrimination in the sense that they took the place of the sample as stimuli controlling the choice of keys. Other observations which support this notion are described below.

Beginning on the 51st session, an attempt was made to photograph the pigeon. When the experimental box was opened for this purpose, the bird stopped matching

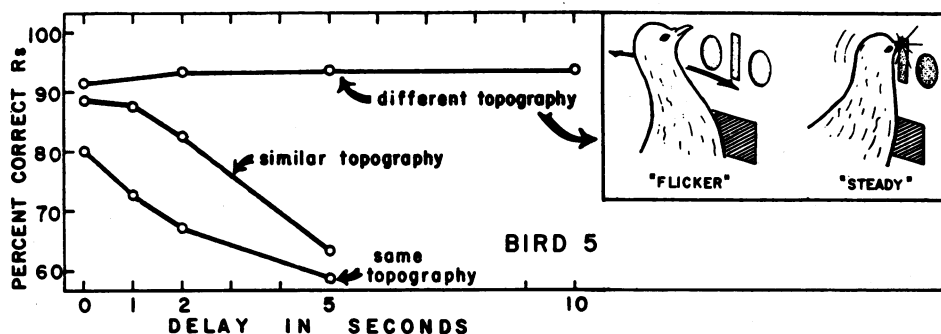


Figure 2. Matching performance of Bird 5 as a function of delay. The different curves correspond to different periods during the experiment. Each point represents mean data from 5 to 10 sessions. (See text.) The inset indicates the bird's delay behavior at the time when the data shown in the upper curve were collected.

(better than chance) at the long delays. After a number of sessions the box was closed once more and the bird was placed on a program of delays including 0, 1, 2 and 5 seconds. The mean of the first 10 sessions on this new program is shown in the lowest curve of Fig. 2. The bird continued a rather stable performance at this low level for about 35 sessions; and then, shortly before the experiment terminated,<sup>3</sup> the bird shifted to a new level of performance illustrated by the middle curve of Fig. 2 (mean of last five sessions).

The stereotyped behavior patterns of the bird varied in an interesting way during the sessions just described. During the early sessions on the new program (lowest curve, Fig. 2), stereotyped behavior continued but it was not differentiated. The bird pecked at and to the right of the sample during the delay regardless of the stimulus conditions. The higher performance level reached at the end of the experiment was accompanied by a re-differentiation of the stereotyped behavior into two response chains. These chains had quite similar topography. Rapid pecking above the right key followed a flickering sample, while rapid pecking to the right and above the sample followed a steady sample. Responses of one sort frequently drifted into the other during the 5-second delay.

#### *Bird 1*

Bird 1 received the same initial training as Bird 5; two sessions with zero delay, then sessions with delays progressively increased, up to a program including 0-, 2-, 5-, and 10-second delays after the sixth session. The bird made relatively few correct matches (less than 70% at zero delay), so the delays were shortened after the 12th session. Subsequently, the bird maintained a rather effective performance over 40 sessions with delays of 0, 1, 2, and 5 seconds. (See left side, Fig. 3.)

Visual observations, begun during this period, revealed stereotyped behavior chains. With a flickering sample, the bird pecked at the top edge of the sample with a kind of biting motion; with a steady sample, the bird spent the delay interval pecking directly at the center of the sample. It is noteworthy that the force and rate of these responses, as well as their form and location, were differentiated. The "flicker" pecking was rapid and so hard that a series of thumps could be heard outside the box. The "steady" pecking was slow and of medium strength. As with Bird 5, these responses occasionally drifted in topography during the delay. Incorrect choices characteristically followed such drifts.

The matching performance of Bird 1 improved markedly between the 60th and 70th experimental sessions. Visual observations disclosed that the location of the response associated with the steady sample had shifted to the right an inch or two, and now only infrequently did one response drift into the other during the delay. Figure 3 shows the change in percent correct responding between the 60th and 70th sessions that accompanied this transition in the topography of the behavior during the delay.

Observations had suggested that both Bird 1 and Bird 5 might to some extent be responding to their own dim reflections in the shiny aluminum panel around the keys. On Session 75 (arrow, Fig. 3), this panel was covered with grey cardboard.

<sup>3</sup>The effects of a number of drugs upon delayed matching were studied, beginning at this point. Some of the results have been published (Blough, 1957).

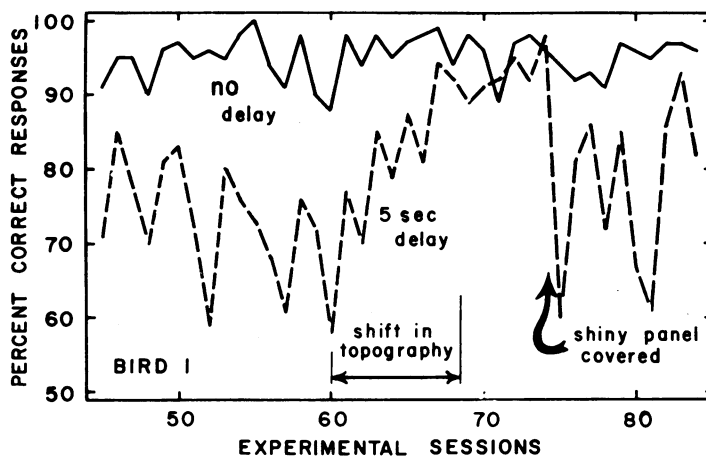


Figure 3. Matching performance of Bird 1 at minimum and maximum delays (0 and 5 seconds) as a function of experimental session. (See text.)

The mediating behavior of Bird 1 failed to appear in the next session, and the bird's matching performance was unstable in subsequent sessions. Eventually, the cardboard was removed and the efficient performance recovered.

*Birds 64 and 71*

Birds 64 and 71 worked with no delay during the first five sessions. Then, delays were introduced and gradually increased in duration. After 22 and 24 sessions, respectively, the birds were placed on their final delay schedules. Bird 64 received delays of 0, 0.6, 1.2, and 2 seconds. Bird 71 received delays of 0, 1, 2, and 5 seconds. It should be noted that these birds had a much longer exposure to no delay and short delays than did Birds 5 and 1.

Figure 4 shows the percent correct matches made by Birds 64 and 71 during the experiment at the minimum ("0 second") and maximum delays. The performances did not change substantially after the first 25 sessions. Figure 5 shows the matching performance of the birds during the relatively stable period late in the experiment. Each point represents the mean of data from the bird's last 30 sessions. Both birds exhibited striking superstitious behavior during the presentation of the sample and in the delay periods. In neither bird did this behavior occur as two distinct patterns, nor did it appear to "mediate" the discrimination. Bird 64 spent each delay pecking at the top of the sample bar, while Bird 71 pecked abortively at or around the left key. In both birds this behavior developed during the very first day of the experiment and remained substantially unchanged thereafter.

DISCUSSION

*Matching as a Function of Delay*

In this experiment, a sample stimulus maintained some control over the pigeon's subsequent choice behavior for a few seconds after the sample had disappeared. In two birds, 64 and 71, this control decreased regularly as a function of the delay in-

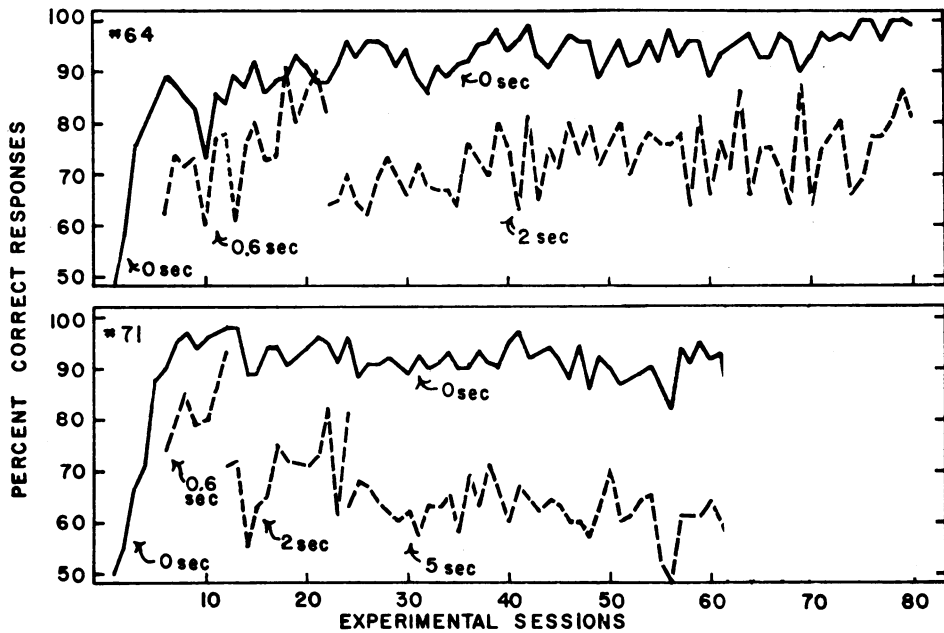


Figure 4. Matching performance of Birds 64 and 71 at minimum and maximum delays as a function of experimental session. The minimum was always no delay ("0 second"); the different maxima are noted.

interval, and the matching performance was relatively stable over many experimental sessions. In the other birds, 5 and 1, stimulus control across the delay varied during the course of the experiment. Sometimes, control was very high over the full range of delays. In the latter birds, but not in the former, the behavior during the delay interval seemed to determine the matching response. Though all four pigeons made

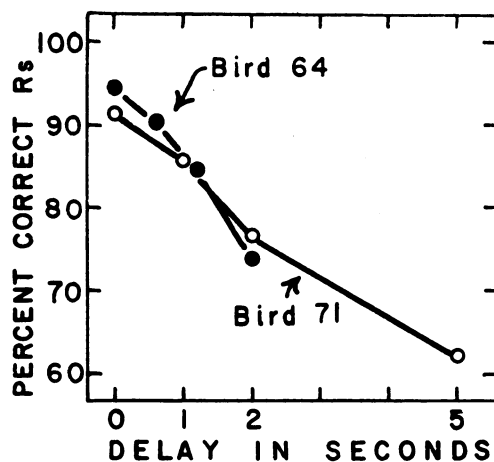


Figure 5. Matching performance of Birds 64 and 71 as a function of delay. Each point represents the mean of data from 30 sessions.

repeated, stereotyped responses during the delay interval, Birds 5 and 1 each developed two topographically different chains of behavior. Each chain corresponded to one condition of the sample stimulus. Several observations support the idea that these chains "mediated" the delayed matching behavior. First, long delays were not bridged in the absence of such behavior chains. Second, the degree of stimulus control varied when the topography of the behavior chains varied. Third, incorrect responses typically followed the occurrence of the "wrong" chain.

How do such mediating chains develop? The following paragraphs present a tentative account of this process.

The appearance of some sort of stereotyped behavior during the delay interval was to be expected, for reproduced here was the essential condition for the appearance of "superstitious" behavior (Skinner, 1948). That is, the pigeons received frequent reinforcement that was not contingent upon the immediately preceding behavior. No matter what the bird did while the sample was on, or during the delay interval, the key lights appeared and a single peck brought food on at least half of the trials. Random movements of the bird just before the key lights appeared were superstitiously strengthened into stereotyped patterns, in the manner outlined by Skinner (1948).

Why did two superstitious chains appear (in two birds), each chain associated with one of the two sample conditions, flicker or steady? The "sensory superstition" of Morse and Skinner (1957) accounts for the first phase of this process. Morse and Skinner point out that a stimulus present when a response is reinforced acquires control of that response, even when the conjunction of the stimulus and the response is only accidental. If two stimuli alternate, and reinforcement occurs periodically, it is likely that by chance one pattern of superstitious behavior will develop in the presence of one stimulus, while another pattern comes to be controlled by the other stimulus. These conditions are fulfilled in the present experiment, if one identifies the two sample conditions as the two stimuli, and neglects the fact that reinforcement does not occur when the stimuli are actually present, but shortly thereafter.

Following the "superstition" paradigm, it is assumed that at some point during the early sessions of Birds 5 and 1, two behavior chains were related at a better-than-chance level to the two sample stimuli. This having happened, another reinforcement contingency began to operate. For, to the extent that the superstitious chains were correlated with the sample stimuli, they themselves provided discriminative stimuli for the matching responses. Pecks on the flickering key were always reinforced following one of the superstitious chains, and never reinforced following the other chain. The opposite was true of pecks on the steady key. This differential reinforcement strengthened the correct response in the presence of the appropriate chain and ultimately strengthened the chain itself and its association with one of the sample stimuli.

The entire development of mediating behavior is seen as a self-strengthening process that may proceed rapidly from small beginnings. It might be noted that once they begin to control matching responses, the stereotyped chains cease by definition to be "superstitious," since they result in an increased rate of reinforcement.

If this account is correct, why did only two of the four birds develop mediating behavior? The present experiment does not answer this question, but it suggests an hypothesis,<sup>4</sup> as follows: the superstitious conditioning of different forms of behavior in the presence of two different stimuli ("sensory superstition") requires a certain initial diversity in behavior. That is, for two chains to be conditioned, behavioral material for two chains must be on hand. Now, Skinner (1948) pointed out that the longer the interval between reinforcements, the more diverse will be the superstitious behavior of the bird, because longer intervals allow more time for any specific bit of behavior to extinguish. Applying this principle to the present experiment, we note that Birds 64 and 71 did not develop mediating behavior, and these are also the birds that were given substantial initial training on a 0-delay schedule, which corresponds, in the superstition experiment, to a short interval between reinforcements. Birds 5 and 1, which developed mediating chains, were the birds that had long delays early in the experiment. It seems possible that the long delays served to diversify the superstitious behavior of Birds 5 and 1, and prevented them from falling at an early stage into a single fixed-response pattern. Birds 64 and 71, with 0 and short delays, never escaped from the firmly conditioned superstitions that they began on the first day of the experiment, before the matching discrimination had been learned.

This analysis of mediating behavior has much in common with the accounts of Ferster (1953) and of Verhave (1959), who explained the effectiveness of delayed reinforcement by reference to superstitious behavior during the delay interval. However, the present situation is more complex than the delayed-reinforcement experiments, and a number of loose ends remain to be pinned down. Are long delays necessary for mediating behavior to develop? Do these delays actually diversify superstitious behavior? Is the fact that a variety of delays were presented an important feature in the development of mediating behavior? Would the results differ if the birds were required to mismatch rather than to match? These and other questions remain to be answered. Whatever its complete explanation, the mediating behavior presents an interesting example of the development of complex, "meaningful" behavior from random behavior, as a result of the operation of the laws of reinforcement.

#### *Related Analyses of Delayed Responding*

There have been frequent reports of the mediation of delayed discrimination by overt behavior, beginning with Hunter's initial paper on the subject (1913). The mediating behavior described heretofore has typically consisted of maintained postural orientation toward a correct stimulus. There is probably no mystery to the behavioral mechanism involved in these cases. The animal comes to the delayed-response situation with some tendency to look toward the correct stimulus, and this behavior is strengthened when it leads to correct responding.

However, in many studies no behavioral mediation has been reported; and in the present experiments, two birds did not exhibit mediating behavior. What can be

<sup>4</sup>The basic idea here might be tested by a variation of the "sensory superstition" experiment. It would be predicted that with stimulus conditions alternating periodically, relatively infrequent "free" reinforcement would favor the appearance of different behavior in the presence of the two stimuli, while, with very frequent reinforcement, behavior under the two stimuli might be identical or quite similar.)



said of these cases? One possibility is that covert chains of behavior may maintain stimulus control in much the same way that overt chains maintain it. The present study does not specifically suggest or deny this possibility. A few experiments do suggest such a continuity. In human subjects, for example, verbal behavior often appears to have similar properties whether it is overt or covert (Skinner, 1957), and the two sometimes occur almost interchangeably. Spiker (1956) found that pre-school children did better in delayed-response experiments when they knew names for the stimuli involved than when they did not. It is interesting to compare the children's verbal behavior with the pigeons' symbolic chains: "...nine of the 27 *Ss* spontaneously verbalized the name of the baited box during the delay periods, sometimes repeating the name several times during a single delay period" (page 111). It seems possible that with these children a behavior chain that only occasionally appeared overtly functioned in the same manner as the pigeons' mediating responses.

There are reports of still other cases in which, due to the length of the delay or the variety of intervening activity, the presence of covert chaining does not seem probable. It may be, as Cowles (1941) and others have suggested, that the behavioral processes involved in such cases are essentially the same as those that occur when a discrimination is learned and retained. That is, a stimulus gains discriminative control during its presentation in the pre-delay period ("one-trial learning"), and retains this status upon its subsequent presentation in the same way that an ordinary discrimination is learned and then retained from day to day or from year to year.

Finally, it is possible that in some cases stimulus control is maintained through time (especially over very short intervals) in a way that cannot be reduced to other processes of conditioning. For example, the curve of Birds 64 and 71 in Fig. 5 (no mediating behavior) might represent a "decay time" of stimulus control that is a basic behavioral fact in its own right.

#### SUMMARY

Pigeons "matched" a flickering or steady "sample" by pecking the correspondingly illuminated response key. Brief reinforcement with grain followed each correct peck. Delays of from 0 to 10 seconds intervened between the disappearance of the sample and the illumination of the response keys. Four predetermined delays appeared in random order during a given experimental session. Each session consisted of 400 correctly matched presentations. The results were expressed in terms of percent correct responses at each of the delays used.

The principal findings were as follows:

1. In two birds the percentage of correct matches was a rather stable decreasing function of the delay duration, falling from approximately 90-95% at 0 second to 60-70% at 5 seconds.
2. In another pair of birds, the percentage of correct matches was an unstable function of delay. The best consistent performance recorded was better than 90% correct at a delay of 10 seconds.
3. Stereotyped "superstitious" behavior was observed in all four birds during the delay interval. In the birds mentioned in (1) above, this behavior was a single,

stable, repetitious response pattern. In the birds mentioned in (2) above, different stereotyped responses were associated with each of the two stimulus conditions (flickering and steady light). In the latter cases, the stereotyped behavior appeared to control the choice responses and it was, therefore, referred to as "mediating" behavior. The mediating behavior varied in topography, and instability of the matching performance was attributed to this variation.

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