FORGETTING AND CONDITIONED SUPPRESSION: ROLE OF A TEMPORAL DISCRIMINATION¹

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Several experiments have found complete retention of conditioned suppression when overall suppression to the signal for shock was measured. The present experiment examined retention of conditioned suppression but did so with a paradigm that produced temporal discrimination of shock occurrence. Nine rats were exposed to a flashing light signal of 5-min duration that always terminated with a shock. After several months, a temporal discrimination was well established, as shown by maximum suppression toward the end of the signal period. After remaining in the home cage for 25 days, the rats were again subjected to the conditioning procedure. The overall level of suppression remained the same but the temporal discrimination was not observed.

Kimble (1961) cites eight separate reports before 1950 to support his contention that "conditioned responses show only a very limited tendency to diminish with the passage of time" (p. 281). This statement is true today of the conditioned suppression literature. Hoffman and his associates (Hoffman, Fleshler, and Jensen, 1963; Hoffman, Selekman, and Fleshler, 1966) found virtually complete retention of well established conditioned suppression to a tone stimulus in pigeons with repeated tests after varying rest intervals as long as 2.5 yr. Gleitman and Holmes (1967) found no decrement in retention when acquisition of conditioned suppression was interrupted after four trials by a 90-day retention interval.

On the other hand, a number of reports describe sizable retention decrements of food-reinforced instrumental behavior (Gleitman and Bernheim, 1963; Gleitman and Steinman, 1963, 1964; Gleitman, Steinman, and Bernheim, 1965; Kehoe, 1963). It is difficult to abstract any one common dimension from these studies that might be responsible for the retention decrements. However, two of these studies (Gleitman and Bernheim, 1963; Gleit-

man *et al.*, 1965) reported a disruption of fixed-interval (FI) performance after a retention interval. The scalloped responding characteristic of this schedule of reinforcement was attenuated by an increase in the number of responses during the first half of the fixed interval.

Presumably, FI performance reflects a process of temporal discrimination. Recently, an analogous type of temporal discrimination has been reported with the conditioned suppression procedure (Millensen and Hendry, 1967; Zelinski, 1966). After prolonged conditioning with a long-duration conditioned stimulus (CS), greater suppression was observed toward the end of the CS period than at the beginning; the suppressed operant showed an inverted scallop during the CS period. Following the Pavlovian terminology, these recent reports have termed this effect "inhibition of delay". The fact that the pattern of responding controlled by an FI schedule of reinforcement is attenuated by a retention interval suggests that the pattern of suppression found after prolonged conditioning to a long-duration CS might show similar forgetting.

METHOD

Subjects

Nine experimentally naive rats of the Sprague-Dawley strain, weighing between 250 and 300 g at the start of the experiment, served as subjects. They were housed individually and had continuous access to food, but limited

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access to water, for 15 min out of each 24-hr period.

Apparatus

Nine aluminum chambers 9 by 9 by 7.75 in. (23 by 23 by 20 cm) inside dimensions, were housed inside sound-attenuating ice chests and were equipped with a stainless-steel grid floor, a solenoid-operated water dipper, a frosted glass lens, and a single bar fashioned from a microswitch that required 20 g (0.196 N) to operate. The CS was a flashing light (0.5-sec on, 0.5-sec off) produced by a 7.5-w bulb behind the frosted glass. Electric grid shock was produced by individual scramblers (Hoffman and Fleshler, 1962) and 1200 v ac constant current sources. Appropriate timers and relays automatically arranged stimulus and response contingencies. Responses were recorded on an event recorder.

Procedure

The rats were maintained on a watering schedule such that they were deprived 21.5 hr at the start of each experimental session. All rats were shaped to press a bar for continuous water reinforcement during one or two initial sessions. For the remainder of the experiment a variable-interval 1-min (VI 1-min) schedule of reinforcement was in effect during each of the daily sessions. These sessions occurred every day except during the retention period.

A conditioned suppression procedure was superimposed upon this variable-interval baseline after 10 hr of training. Three conditioning trials, each of which consisted of a 5-min light that terminated with a 0.7-mA grid shock, were spaced randomly throughout each session. Lower intensity (0.3 mA), unsignalled shocks occurred at random but only in between the conditioning trials with a density of 10 shocks per session. The intended purpose of these low-intensity shocks was to make the apparatus cues slightly aversive to a rat and thus provide a contrast to the first few minutes of the CS period, during which neither low- nor high-intensity shocks occurred. In other words, the low-intensity shocks might magnify the observation of temporal discriminative behavior during the CS period. After 14 sessions of conditioning, the number of conditioning trials per session was increased to four. This procedure was then continued for another 40 days for a total of

54 conditioning sessions and 202 conditioning trials. At this point the rats were maintained in their home cages for an additional 24 days in order to examine retention. During this period in the home cage, the rats were treated in a manner similar to that of the previous phase; they were maintained on the same deprivation schedule and handled daily, but they were never placed in the apparatus and therefore were not exposed to either the operant or Pavlovian contingencies of the experiment. At the end of the retention interval, the procedure used during the later conditioning sessions was reestablished.

Bar-press responses emitted during the 5 min before the CS and during the 5-min CS itself were measured by calculating suppression ratios for each minute during the CS presentation. This ratio is of the form $B/(A + B)$, where B is the rate during a single minute of the CS and A is the mean rate per minute for the 5-min period before the CS. Mean daily ratios per minute were also computed by averaging these ratios per minute defined as above for all four daily trials.

RESULTS

Acquisition

As described above, temporal discrimination of shock occurrence would be shown by maximal suppression toward the end of the CS period and a graph of suppression ratios for each minute of the CS period would show a negative slope. This pattern of suppression, which reflects a temporal discrimination by the rat, is referred to as the temporal discrimination pattern.

When the mean suppression ratios per minute for all nine rats taken together (group curve) were examined on a day-to-day basis, the temporal discrimination pattern did not appear consistently until after the seventieth trial. Before this trial there appeared to be several stages in the development of the final pattern. At first there was no suppression at any time throughout the CS period. Then, from Trial 10 to 20, there was relatively even suppression through the entire CS period; next, during Trials 30 to 50, the greatest degree of suppression occurred during the first minute of the CS period. This pattern of conditioned suppression has also been observed by Rescorla (1968) after a moderate amount of

Fig. 1. Baseline stability: mean suppression ratios per day plotted across minutes of CS duration for individual rats. Each graph shows the amount of inhibition of delay for the second through the sixth day before the retention interval. These days are designated by the numbers at the top of the entire figure.

acquisition and it is the opposite of the temporal discrimination pattern. This pattern of decreasing suppression during the CS period was then gradually replaced by relatively even but moderate suppression throughout the CS period and then finally the development of the temporal discrimination pattern (increasing suppression during the CS period).

Asymptotic Behavior

Figure 1 shows the data of individual rats in terms of mean daily ratios per minute for five consecutive days prior to the day before the retention interval. Each graph is based on 20 trials (number 179 to 198, four trials per day, five curves for each rat). The individual

Fig. 2. Forgetting: mean suppression ratios per day plotted across minutes of CS duration for individual rats. Each graph shows the amount of inhibition of delay on the first day before the retention interval and for the first day after.

curves for all nine rats showed some evidence of a negative slope, the temporal discrimination pattern; but the stability and magnitude of this slope varied widely from rat to rat. The graphs for each rat were ordered from left to right on the basis of the steepness and consistency of the slope of the curves for each day.

Retention

Figure 2 shows the mean daily ratios per minute for the day immediately before the retention interval (mean for Trials 199 to 202) and the day after (mean for Trials 203 to 206). Thus, Fig. 1 and 2 together contain the six daily curves before retention and one daily

curve after. Once again the individual curves in Fig. 2 were ordered from left to right but this time on the basis of the magnitude of forgetting. Six rats (9, 3, 6, 8, 2, and 1) showed complete loss of the temporal discrimination pattern after the retention interval. Two more (7 and 5) showed some evidence of forgetting and the last (4) showed evidence of retention. By comparing these data with the asymptotic behavior data of Fig. 1, there appears to be a relationship between the stability and magnitude of the temporal discrimination pattern and the amount of forgetting. The exception is Rat 3, whose retention graph is probably misleading in view of this rat's unstable asymptotic performance.

Statistical Analysis

The findings of this experiment can also be substantiated statistically. A ratio score was computed based on the suppression ratios per minute for the first and last minute (again of the nature $B/A + B$ but in this case B represented the ratio per minute for the last minute, and A represented the ratio for the first minute. There was a significant difference between the group mean ratio for the last trial (number 202, mean ratio = 0.33) before the retention interval and the mean (number 203, mean ratio = 0.60) for the first trial after ($t = 3.25$, $df = 8$, $p < 0.02$).

DISCUSSION

This study demonstrated that forgetting can be observed with the conditioned suppression technique when attention is focused on the pattern of responding that reflects a temporal discrimination of shock occurrence. There was no retention decrement in the overall level of suppression when all nine rats were considered as a group; this agrees with earlier reports (Gleitman and Holmes, 1967; Hoffman *et al.*, 1963; Hoffman *et al.*, 1966), but there was a marked change in the pattern of responding during the CS interval.

The patterning of responding during a long-duration CS has been labelled "inhibition of delay" (Pavlov, 1927; Rescorla, 1967) and is attributed to the dual processes of excitation and inhibition. The absence or attenuation of the conditioned response during the early portion of the CS period is attributed to the action of Pavlovian conditioned inhibi-

tion (Rescorla, 1969). When this analysis is applied to studies of conditioned suppression, the decrease in responding produced by the signal associated with shock is attributed to excitation and the lack of such a decrease produced by a safety signal or stimulus associated with the absence of shock is attributed to inhibition. Some may find this usage confusing because an inhibitory CS could lead to increased responding in the present situation. This confusion appears to stem from an identification of the Pavlovian terms excitation and inhibition with specific changes in responding. According to such literal interpretation of these terms a conditioned aversive stimulus (CAS) would be excitatory when presented during avoidance responding but inhibitory when presented during operant responding for appetitive reinforcement. Clearly, such usage represents a perversion of Pavlovian theory. The CAS is an excitatory stimulus in all situations where it produces behavioral change as a consequence of its previous positive contingency with regard to shock. In keeping with Rescorla's (1969) general definition of Pavlovian conditioned inhibition, a safety signal is inhibitory because of two attributes; it has had a negative contingency with shock, and it "reduces some behavioral change which is normally attributed to excitation" (p. 78). In the present situation then, an inhibitor must have had a negative correlation with shock and must also reduce conditioned suppression. The early portion of the long-duration CS could meet these qualifications and therefore, the temporal discrimination is said to be mediated by a combination of excitation and inhibition.

According to the analysis above, the previous studies that found strong retention of conditioned suppression involved only simple conditioned responses which could be attributed entirely to the process of excitation. This suggests, then, that it was the addition of the inhibitory process that led to the observation of forgetting in the present study. Furthermore, in the general case, it may be found that forgetting of conditioned responses is related to the competition between excitation and inhibition which is mediating the same response. One reason for emphasizing the competition between the two processes, rather than just the forgetting of the inhibitory process alone, is based on the outcome of the present study.

If the retention interval resulted in a loss of the inhibitory process, then one would expect an increase in the overall level of conditioned suppression which, of course, did not occur. Since the earlier studies on forgetting of conditioned suppression seemed to rule out forgetting of the excitatory process alone, this leaves the interaction between the two processes as the most likely correlate of forgetting of conditioned responses.

We believe that the present findings are probably not the result of the reintroduction of shock into the situation during the test session after the retention interval. During the first presentation of the CS in this last session, eight of nine rats showed more suppression during the first as compared to the last minute of the CS period (*i.e.*, forgetting of the temporal discrimination). This first CS presentation occurred before any shocks were introduced in that session. Thus, any explanation of the empirical findings of forgetting (loss of performance after a retention interval) in terms of changes in adaptation to the shock occurring during the retention interval would seem unwarranted. The reason for presenting the data as averaged over four trials after the retention interval and for reintroducing shock was to keep the stability of the daily ratios and the comparability of these curves to the earlier days before the interval.

Finally, we feel that the major value of the present study is the demonstration of a viable procedure for studying forgetting of conditioned suppression, and the suggestion that Pavlovian conditioned inhibition may play an important role in studies of animal forgetting.

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