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CS Memory after Trace Conditioning

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Two experiments investigated successive discrimination learning in rats. Of central interest was the influence of the interval between the reinforced stimulus (S+) and the reinforcer (shock) on discriminative performance. Experiment 1 demonstrated that when shock immediately followed the S+ the discrimination was formed rapidly—subjects quickly came to show conditioned responding exclusively during the S+. However, when there was a 30-s trace interval between the S+ and shock the discrimination was only poorly formed, and conditioned responding occurred on both S+ and nonreinforced (S−) trials. In Experiment 2 subjects received concurrent training on a visual and an auditory discrimination. For one discrimination the S+ was immediately followed by shock and for the second discrimination there was a trace interval between the reinforced cue and shock. The former discrimination was acquired more readily than the latter. Implications of these results for contemporary theories of discrimination learning are explored and parallels between these results and the phenomena of contrast and of "marking" are examined. © 1992 Academic Press, Inc.

Pavlov observed that after successful conditioning with one stimulus other stimuli "spontaneously acquired similar properties" (Pavlov, 1927, p. 113). For example, he reported that establishing one tone as a signal for food enabled other similar tones to elicit the conditioned response (CR) of salivation. This phenomenon, known as stimulus generalization, is readily explained by assuming that a CS (conditioned stimulus) activates a number of representational elements and that some of these, the common elements, are also activated by other stimuli (see, for example, Estes, 1950; Pearce, 1987; Rescorla, 1976; Wagner, 1981). The degree to which a given test stimulus elicits generalized responding will then reflect the CR acquired by the common elements during conditioning. Pavlov (1927, p. 113), however, described the results of a study by Grossman that appear to be inconsistent with this account of generalization. Grossman's study examined the influence of a trace interval between the CS and US (un-

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conditioned stimulus) on stimulus generalization. It is well established that trace conditioning often results in the development of a weak CR to the CS (e.g., Kamin, 1965). Accordingly, this conditioning procedure should reduce the CR elicited by the common elements and reduce generalized responding. Grossman's study, however, indicated that generalization was particularly marked after trace conditioning.

Pavlov (1927, p. 117) had no principled account for Grossman's observations, but suggested that the (effective) CS established by a trace conditioning procedure might be more similar to other test stimuli than the effective CS trained with no trace interval. This account, and the observations on which it was based, seemed to us to be sufficiently intriguing to justify more systematic study. In particular, the study reported by Pavlov did not include a condition in which there was no trace interval between CS and US. Consequently, statements about the extent of stimulus generalization rested on comparisons made with the results of other studies. The aim of the two experiments reported here was, therefore, to investigate directly the suggestion that conditioned responding established by a trace conditioning procedure generalizes more readily than responding that develops when the CS and US are contiguous.

EXPERIMENT 1

All rats in Experiment 1 received conditioning trials with one auditory cue, the S+, intermixed with nonreinforced (test) trials with another auditory stimulus, the S−. For one group of subjects, Group I for immediate, presentations of the S+ were followed immediately by the delivery of the US, footshock. Subjects in this group may be expected to develop the CR of fear to the S+; they should also show fear during the S− to the extent that this stimulus is perceived as similar to the S+. Subjects in the second group, Group T for trace, received identical training except that the CS terminated 30 s prior to the delivery of the US. If CRs established using this trace conditioning procedure are more likely to generalize, then Group T should find it more difficult to restrict conditioned responding to presentations of the S+. An advantage of this successive discrimination procedure over the generalization test employed by Grossman is that it permits a number of opportunities to assess the extent of generalized responding.

Method

Subjects. The subjects were 16 male hooded Lister rats with a mean ad lib weight of 367 g (range: 350–385 g). The rats were maintained at 80% of their ad lib weights by restricting the amount of food they received on each day.

Apparatus. Four identical Skinner boxes, supplied by Campden Instruments Ltd., were used. Each had a recessed food tray to which 45-mg food pellets could be delivered. The entrance to this food tray was guarded by a transparent plastic flap, 6 cm high by 5 cm wide, that was hinged along one of its 5-cm edges to the top of the opening to the food tray. Movement of this flap actuated a microswitch, and each closing of the switch was automatically recorded as a single response. The flap returned to its vertical resting position when the subject removed its snout from the food tray. The floor was constructed from stainless steel rods that could be electrified by a Campden Instruments Ltd. shock generator (Model 521C) and shock scrambler (Model 521S). A loudspeaker mounted on the wall opposite the food tray was used to present a tone of 2000 Hz or white noise at an intensity of 80 dB (scale A; re 20 $\mu N/m^2$). This intensity was 16–20 dB in excess of the background noise level that was produced by a ventilation fan. Background illumination was provided by a 3-W jewel light (rated for 24 V but operated at 16 V) mounted 14.5 cm above the food tray. Each box was housed in a sound- and light-attenuating chamber.

Procedure

Magazine and baseline training. The rats initially were trained to retrieve food pellets from the food tray. On the first day of the experiment, food pellets were delivered on a variable-time 60-s schedule during a 40-min session. The flap was fixed in a raised position during this session to help rats locate and retrieve the food pellets. The procedure on the second day was identical to the first with the exception that the flap was returned to its resting position so that the rats were required to move the flap in order to gain access to the food tray. Following magazine training the subjects were randomly assigned to either Group I or Group T. In the next four 40-min sessions pushing the flap was trained as an instrumental response. During the first of these sessions each push was reinforced by the delivery of a single food pellet until 75 pellets had been earned and then the subject was removed from the Skinner box. In the next session responding was reinforced according to a variable-interval 30-s (VI30) schedule, and in the following two sessions responding was reinforced on a VI60 schedule.

CER training. On the next six days subjects received two 30-s presentations of one auditory cue (the S+) and two 30-s presentations of a second auditory stimulus (the S−) in a 40-min session. For subjects in Group I the delivery of a 0.4-mA shock immediately followed the S+, whereas for Group T there was an interval of 30 s between the offset of the S+ and the delivery of shock. The S− was presented without consequence. The first trial was presented 440 s after the beginning of each session and the intertrial interval (ITI) was 500 s. The order in which the trials were presented was random. The design was counterbalanced so that for half of the subjects in each of the groups the noise served as the

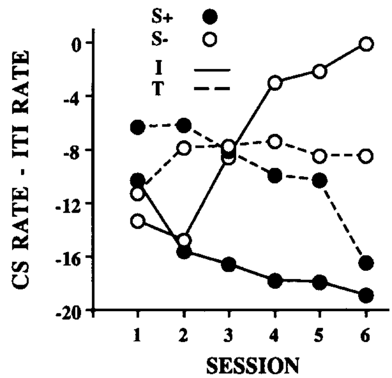

FIG. 1. Experiment 1. Group mean suppression scores during discrimination training in which one stimulus, the S+, was followed by shock a second cue, the S−, was not reinforced. In Group I the presentation of shock immediately followed the offset of the S+, and in Group T the delivery of shock occurred 30 s after the S+.

S+ and the tone as the S−, and for the remaining subjects this arrangement was reversed.

The tendency of the stimuli to suppress instrumental responding was expressed as a difference score that took the form: Response rate in the presence of the target events minus response rate in the remainder (target-free) of each session. Using this score, therefore, negative scores indicate the suppression of responding.

Results

Inspection of the difference scores recorded during CER training revealed no systematic differences based on which stimulus (tone or noise) was assigned as the S+ and the S−. The results of the six days of CER training depicted in Fig. 1 and analyzed below, therefore, are collapsed across this (counterbalanced) factor. It is apparent that during the first three sessions subjects in Group I tended to show greater suppression of baseline responding during the target events than did subjects in Group T. This difference presumably reflected that suppression to the S+ developed more rapidly in Group I and tended to generalize to presentations of the S−. On the remaining sessions, however, subjects in Group I came to suppress responding only on S+ trials, and responding in the presence of the S− did not differ markedly from the rate of responding in the ITI. On the other hand, subjects in Group T continued to show suppression of responding on both S+ and S− trials throughout training and failed to achieve the proficient performance shown by Group I at any point.

This description of the results was supported by statistical analysis. The rejection level that was adopted for all analyses was $p < .05$. An analysis of variance (ANOVA) with one between-subjects factor (Group) and two within-subjects factors (Session and Stimulus value, S+ or S−) revealed no effect of Group or Sessions ($Fs < 1$); there was, however, an interaction between these two factors, $F(5, 70) = 3.61$. There was also an effect of Stimulus value, $F(1, 14) = 11.99$, that interacted with both Group, $F(1, 14) = 7.77$, and Sessions, $F(5, 70) = 10.53$. There was no three-way interaction between the factors ($F(5, 70) = 1.60$).

In order to explore the interaction between Group and Stimulus value, separate ANOVAs were conducted on S+ and S− scores. The anaysis of S+ scores revealed an effect of Sessions, $F(5, 70) = 6.28$, but no effect of Group and no interaction between these factors (largest $F = 2.59$). Analysis of the S− scores revealed an effect of Sessions, $F(5, 70) = 5.03$, and no effect of Group ($F < 1$). There was, however, an interaction between these two factors, $F(5, 70) = 3.54$. Analysis of simple main effects revealed that the groups differed on the final session of training, $F(1, 45) = 4.36$.

The baseline response rates averaged over all sessions of CER training were 19.01 responses per minute (rpm) in Group I and 14.34 rpm in Group T. These scores did not differ reliably ($F < 1$).

Discussion

The results of Experiment 1 show that discrimination learning proceeds less rapidly when there is a trace interval between the S+ and the US than when the presentation of the US is contiguous with the S+. This pattern of results is difficult to explain in terms of standard theories of associative learning. Thus although such theories allow that trace conditioning might result in a less vigorous CR to the S+, they predict that this difference should also be reflected in the level of (generalized) responding shown on S− trials. But in fact, Group T showed more responding on S− trials than did Group I.

The pattern of results observed in Experiment I are consistent, however, with Pavlov's (1927) claim that trace conditioning results in marked generalization. Performance in a discrimination will be determined in part by the degree to which associative strength acquired by the S+ generalizes to S−. A discrimination will be poorly formed, therefore, when there is an interval between the S+ and the US. And our results, thereby, provide support for Pavlov's suggestion that the *effective* CS established during trace conditioning is, in some way, more similar to other test stimuli than the CS established when there is no trace interval. However, before we examine this suggestion, and other possible interpretations of the results of Experiment 1, it seemed worthwhile to confirm the reliability and to assess the generality of the effects observed in Experiment 1.

EXPERIMENT 2

In this experiment each subject received concurrent training on two discriminations, one involving immediate reinforcement of the S+, the other trace conditioning. A given subject might receive, for example, presentations of one auditory cue (such as white noise) that were immediately followed by reinforcement and nonreinforced trials with another cue (a tone); it would also receive trace conditioning trials with one visual cue (e.g., onset of a light) and nonreinforced presentations of a second visual cue (a reduction in the level of ambient illumination). If it can be allowed that these two discriminations are likely to proceed relatively independently of one another (in particular, that generalization will occur within a modality but much less so across modalities), then this experimental design should allow a within-subjects demonstration of the effect seen in Experiment 1. In the instance just given, the subject can be expected to form the auditory discrimination more rapidly than the visual discrimination. An advantage of the within-subjects design is that it ensures that the associative strength of the background contextual cues will be the same for all subjects. Although no effect was evident in the baseline response rates, it seems possible that subjects in Group T in Experiment 1 (who received shocks not immediately preceded by an explicit cue) might have developed more contextual fear than subjects in Group I. The present experiment is capable of demonstrating that a difference between the trace and immediate conditions can still be found when no contribution from differences in background fear is possible.

Method

Subjects and apparatus. The subjects were 16 male hooded Lister rats with a mean ad lib weight of 340 g (range: 315–365 g). The rats were maintained in the same way as in Experiment 1. The apparatus was the same as that used in Experiment 1 with the exception that each box was brightly lit by a 30-W striplight (rated for 240 V but operated at 100 V) positioned above the translucent ceiling. The two additional visual cues used in this experiment were: The offset of the striplight for 30 s; the presentation of two jewel lights that were located on either side of the food hopper for 30 s. The presentation of these jewel lights was pulsed at the rate of 60 pulses per minute. Each pulse was 0.5 s in duration, and the interval between successive pulses was 0.5 s.

Procedure. The first stages of Experiment 2 were identical to those of Experiment 1. The rats were trained to collect food pellets from the food hopper and then to push the flap as an instrumental response. On each of the next eight days subjects received four types of trial. On one trial (IS+) the presentation of a cue from one modality was immediately followed by the delivery of footshock, and on a second trial type (IS−)

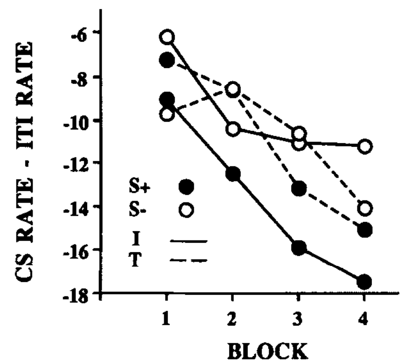

FIG. 2. Experiment 2. Each subject received training on an auditory and a visual discrimination. For one of these discriminations (I) the S+ was immediately followed by shock and the S− was nonreinforced, and for the second discrimination (T) the delivery of shock occurred 30 s after the S+.

a stimulus from the same modality as that used for the IS+ was presented but was not reinforced. On the third trial type (TS+) a stimulus from a different modality was presented and followed by footshock after a 30-s trace interval. The final trial (TS−) was a nonreinforced presentation of a stimulus from the same modality as the TS+. The design was counterbalanced so that for half of the animals the IS+ and IS− were auditory cues and the TS+ and TS− were visual stimuli and for the remainder this arrangement was reversed. The particular stimuli that were reinforced or nonreinforced within a dimension were also counterbalanced. Other details of the experiment that have not been mentioned were identical to those described for Experiment 1.

Results and Discussion

Inspection of the scores revealed that there were no systematic differences between subjects receiving auditory I stimuli and visual T stimuli, and those that experienced the reverse assignment. Within each modality, which stimulus was assigned as S+ produced no systematic effect. Accordingly, the results that are depicted in Fig. 2 and analyzed below are collapsed across these counterbalanced factors.

The results of Experiment 2 replicate, using a within-subjects design, the important aspects of the results of Experiment 1. Thus, inspection of Fig. 2 indicates that initial presentations of each of the four cues suppressed responding to an equivalent extent. Over the course of training, however, the discrimination based on immediate reinforcement, that between IS+ and IS− trials, was easily formed, whereas the discrimination for which the S+ (TS+) was followed after a trace interval by the reinforcer did not develop.

This description of the results was confirmed by statistical analysis. A factorial ANOVA was conducted with Block, Interval (trace or immediate), and Stimulus value (S+ or S−) as the factors. This analysis revealed an effect Block, $F(3, 45) = 6.35$, an effect of Stimulus type, $F(1, 15) = 7.88$, and no main effect of Interval, $F(3, 45) = 1.29$. There were interactions between Block and Interval, $F(3, 45) = 3.06$, between Block and Stimulus value, $F(3, 45) = 3.75$, and between Stimulus value and Interval, $F(1, 15) = 6.05$. The three-way interaction was not significant ($F < 1$). The rate of responding in the ITI by subjects in Experiment 2, of 15.96 rpm, was similar to the rates of responding of Groups I and T in Experiment 1.

A further analysis was conducted on the terminal level of discriminative performance, on the final block of training. This analysis revealed no effect of Interval ($F < 1$), an effect of Stimulus value, $F(1, 15) = 10.14$, and an interaction between these two factors, $F(1, 15) = 5.61$. This interaction was further analyzed using an analysis of simple main effects. This analysis revealed that the S+ and S− scores differed for the discrimination based on immediate reinforcement, $F(1, 15) = 13.30$, but the subjects did not respond differentially on the S+ and S− trials for the trace conditioning discrimination ($F < 1$). It also revealed that the S+ scores did not differ, $F(1, 15) = 2.64$, but, that the level of suppression was greater on TS− trials than IS− trials, $F(1, 15) = 4.61$.

GENERAL DISCUSSION

The experiments described above have shown that rats will learn a successive discrimination less readily when a delay intervenes between the S+ and the presentation of the reinforcer than when the S+ and reinforcer are contiguous. This outcome is not a simple consequence of the fact that acquisition of the CR to the S+ tends to occur more rapidly with immediate reinforcement than with the trace procedure. Rather, the main source of the effect is in the different levels of responding to the S− generated by the two training procedures. Any explanation of the effect will need to focus on the processes determining generalization between the S+ and S−. Analysis of such processes can be clarified by characterizing the S+ and S− as being composed of various elements some of which are unique to the S+ or the S− and some common to both. The S+ (stimulus A) may be taken to consist both of unique *a* elements and of *c* elements that it holds in common with stimulus B (the S−). B will have its own unique, *b*, elements. Generalization between A and B will depend on the ability of the *c* elements to evoke responding.

If trace conditioning were more effective than immediate reinforcement in endowing the *c* elements of stimulus A with associative strength then the results of our experiments would follow. There is nothing, however, in standard associative theorizing (e.g., Wagner, 1981) to generate such an effect—according to such theories the associative strength acquired by both *a* and *c* elements will be greater after immediate than after delayed reinforcement. It is necessary to add some new assumption therefore; for instance, that the effective stimulus in trace conditioning is the memory of the CS active at the time of reinforcement and that the *c* elements of the CS are less easily forgotten than the *a* elements. Pavlov's (1927) account of superior generalization after trace conditioning appears (his arguments are somewhat obscure) to be based on a notion of this sort—his account may be taken as suggesting that the effective CS in trace conditioning will be more like the test stimulus than will the effective CS established by immediate reinforcement. Unfortunately, however, Pavlov offers no good reason why his analysis should be accepted and the suggestion that *c* elements are preferentially strengthened in trace conditioning remains arbitrary and thus unsatisfactory.

We consider next two further possible interpretations, both of which accept that the *c* elements are likely to gain more strength when reinforcement is immediate than when it is delayed, but which identify other factors that determine the level of responding observed on B stimulus test trials.

One possibility is that more inhibition is generated on S− trials when there is no delay of reinforcement on S+ trials than when a trace conditioning procedure is employed. It may be assumed that inhibition will be acquired by the unique elements of the S− (*b* elements) as a consequence of their nonreinforcement in the presence of excitatory *c* elements. Since the *c* elements will acquire more excitatory strength on S+ trials in the I condition than in the T condition, the inhibitory strength of the *b* elements should be greater in the former condition. But the greater inhibitory strength of the *b* elements in the I condition can only be expected to cancel the greater excitatory strength of *c*. Some other factor must be introduced to explain how differences in conditioned inhibition might result in the *net* associative strength of the S− being less in I than T. Perhaps the critical factor is that the initial onset of the stimulus is an element capable of gaining excitatory strength on reinforced trials. This element (in common with other features of the S+) may be assumed to acquire more excitatory strength when reinforcement is immediate than when it is delayed. If its presence on nonreinforced trials will support the acquisition of inhibition by the unique features of the S− then more will develop in the I condition. And since this excitatory cue would not itself be present for the bulk of the trial the inhibitory effect of the unique cues might be visible in performance.

The analysis just presented is essentially similar to that proposed by Mackintosh (1974, p. 395) for simultaneous negative contrast—the observation that responding for a small reward is less vigorous when the S+ signals a larger reinforcer. The effects demonstrated in our experiments can be seen as a special case of such a contrast effect with the level of responding on S− trials being determined by the immediacy (rather than the magnitude) of the reinforcer on S+ trials.

A second possible interpretation of our results emerges from the suggestion that the direct *c*-US association is not the only source of responding seen on the S− trials. To the extent that common elements become associated with the unique (*a*) elements of the S+, then responding might occur on the S− trials because the common elements are able to activate *a* and thereby to evoke the US representation (see McLaren, Kaye, & Mackintosh, 1989). If this association were less well formed when reinforcement occurred immediately after the S+, this would provide one reason why the CR might be less vigorous on S− trials in Group I than Group T. It is well established that associations can develop between two elements of a compound stimulus (e.g., Rescorla & Durlach, 1981). And, it is encouraging to note that there is some evidence to suggest that such associations are only poorly formed when the compound stimulus is immediately followed by some "distracting" event such as a reinforcer (Holland, 1980; see also Rescorla & Durlach, 1981, p. 104). The form of explanation just outlined can also provide a parallel account for simultaneous negative contrast if one supposes that a large reinforcer will be more likely to disrupt the formation of within-event (e.g., *a–c* associations than will a smaller reinforcer.

The results of Experiments 1 and 2, and Grossman's more informal observations, do not help to choose between the accounts developed above. There is, however, a further phenomenon that is of some use in this respect. Lieberman, McIntosh, and Thomas (1979; see also Lieberman, Davidson, & Thomas, 1985) observed that the poor performance of rats in a delayed discrimination could be dramatically improved if the choice to go into the reinforced and nonreinforced alleys in a maze was *marked* by the experimenter picking the rat up or some other salient event. This finding is to be anticipated if what Lieberman *et al.* (1989) refer to as a "marker" is having its effect by disrupting the formation of within-stimulus associations—associations between the unique and common elements of the to-be-discriminated events that could mediate generalization between them.

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