a "conditional discrimination," a term that unfortunately lacks a precise definition. That various animals can be trained to make discriminations of this sort has been demonstrated by a number of investigators [for example (*2*)]. The most significant feature of our results, however, is not that pigeons can make a "conditional discrimination," but that the auditory dimension which controls behavior under condition TR seems to be completely without influence on behavior under condition TNR. The conclusion that auditory dimension is irrelevant to behavior under condition TNR rests upon the results of the generalization test and does not follow from the data obtained in training.

Current theories of "stimulus generalization" are either too incomplete to be applied to our situation or they yield incorrect predictions. Further study of the phenomenon described here may aid greatly in the formulation of an adequate theory of behavior.

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Retrograde Amnesia Produced by Electroconvulsive Shock after Reactivation of a Consolidated Memory Trace

Abstract. *Rats had a memory loss of a fear response when they received an electroconvulsive shock 24 hours after the fear-conditioning trial and preceded by a brief presentation of the conditioned stimulus. No such loss occurred when the conditioned stimulus was not presented. The memory loss in animals given electroconvulsive shock 24 hours after conditioning was, furthermore, as great as that displayed in animals given electroconvulsive shock immediately after conditioning. This result throws doubt on the assertion that electroconvulsive shock exerts a selective amnesic effect on recently acquired memories and thus that electroconvulsive shock produces amnesia solely through interference with memory trace consolidation.*

Impaired retention of responses learned shortly before electroconvulsive shock (ECS) stimulation is commonly called retrograde amnesia (RA), and is attributed to interference with consolidation, a process considered responsible for the structural encoding and consequent long-term storage of memory traces. Uninterrupted completion of this process presumably makes the memory trace relatively permanent and insusceptible to disruption by ECS. Experiments of the single training trial, single ECS paradigm show that RA diminishes and eventually disappears as the time between training trial and ECS increases. Theoretically, memory is consolidated between the time of the training trial and the last time ECS produces some RA. This interval has been thought to last several hours (*1*), or just several seconds (*2*).

Our investigation of the temporal factor in RA was to determine: (i) whether ECS operates solely by interference with memory storage; and (ii) specifically, if ECS, given soon after the selective reactivation of a memory trace laid down at the time of learning, could produce RA long after the learning event. Our subjects were 100 male Sprague-Dawley rats (220 to 270 g), purchased from a commercial supplier. They were kept in individual cages and fed 12 g of food daily.

Fear conditioning was given in a lick chamber with a grid floor, two aluminum walls, two transparent Plexiglas walls, and a Plexiglas ceiling. At the center of one wall, 2.5 cm above the floor, in a 1.5-cm hole, was a glass drinking tube. A drinkometer circuit was completed whenever the subject licked the tube. The chamber was lit by a 10-watt bulb and was in a sound-attenuated compartment with a white interior.

A floorless black plywood box, used during trace reactivation, fit snugly into the lick chamber. A red bulb lit the interior, and a piece of black plastic replaced the Sanicel bedding used beneath the grids at other times. Through a 1.5-cm hole in both the chamber and box, earclips, through which a 0.5-second, 40 ma of ECS was delivered, could be attached to the subjects.

During 5 days before the first treatment, subjects were adapted to earclips for 21 minutes (20 minutes in home cage, 1 minute in black box). Gloves were worn when the clips were attached and removed; the adaption period began 10 to 15 minutes after feeding. Three days before the first treatment, all subjects were deprived of water. After 24 hours of deprivation, the subjects were placed in the lick chamber and allowed to make 110 licks. The drinking tube then protruded 1.5 cm into the chamber; if the subject did not locate and lick the tube in 5 minutes, it was directed to the tube and allowed to make 110 licks. The subjects received their food ration 45 minutes later, with water available for 10 minutes. The session on the following day was similar except that the drinking tube was 3 mm behind the inner-wall surface; the subject remained in the chamber until it located the tube and made 110 licks; no gloves were used to handle the subjects; water was available for the next 24 hours.

After the second session, the subjects were randomly divided into five groups of 20 subjects each, and the next day they all received their first treatment, which was the same for all groups except group 1, a "typical RA group" that served as a control. For this treatment, each subject was removed from its home cage with a gloved hand 10 to 15 minutes after feeding and was taken to the lick chamber where earclips were attached. The chamber was modified, with a white panel over the aluminum wall where the tube had been. After 47 seconds, the conditioned stimulus (CS), an 80-db white noise, was presented for 10 seconds. A 1.3-ma shock was delivered, simultaneously with noise offset, to the grids for 3 seconds. All except group 1 were removed to home cages after footshock; group 1 received ECS immediately after footshock and was then removed to home cages. Water bottles were removed after this treatment.

The next day in the black box, the CS used the day before was presented briefly to reactivate in 40 subjects a memory trace laid down at the time of learning. Afterward, ECS was given to 20 of these subjects and also to 20 other subjects that had not received the brief CS. Thus, CS (a 2-second, 80-db white noise) and ECS were manipulated factorially in terms of occurrence or nonoccurrence. Group 2 was presented the CS and then immediately given ECS. Group 3 received only CS. Group 4 received only ECS, and group 5 received nothing. Groups 1 and 5 received the same treatment in the black box. All subjects were handled without gloves,

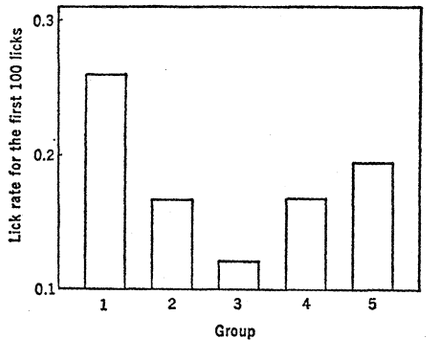

Fig. 1. Mean lick rate [(1/sec) × 100] for the 100 licks before CS onset. This measure was used as an indication of fear to situational stimuli. Group 1, which was given ECS immediately after the fear conditioning trial, displayed the least amount of fear as indicated by its high lick rate. The fear displayed by groups 2 and 4, which were given ECS 24 hours after conditioning, was comparable to that of group 3 and 5 which received no ECS.

wore earclips, and were in the black box for 30 seconds during this treatment. They received food 45 minutes after the treatment with water available for 10 minutes.

During the second treatment, most of the situational stimuli including those from handling (no gloves) and internal cues (from deprivation) differed from those of the first treatment. These changes were introduced because such stimuli, in addition to the specified CS, acquire fear-arousing properties and can reactivate traces laid down during conditioning. Elimination of these stimuli thus resulted in greater temporal control of trace reactivation.

Twenty-four hours after the second

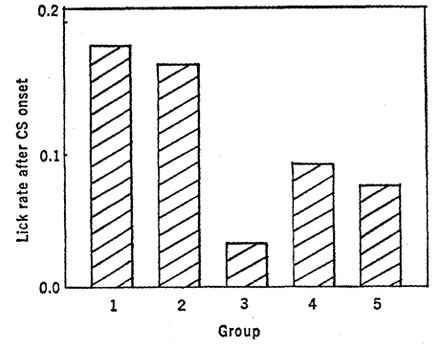

Fig. 2. Mean lick rate [(1/sec) × 10] for 10 licks after CS onset. Group 1 which received ECS immediately after conditioning and group 2 which received ECS 24 hours after conditioning but following memory trace reactivation showed a memory loss for fear conditioned to the CS. Group 4 which received ECS 24 hours after conditioning in the absence of trace reactivation, and groups 3 and 5 which did not receive ECS showed no such loss of memory.

treatment, the subjects were returned to the lick chamber for a test session like the second one, except that on the subject's 100th lick the CS came on and remained on until the subject made ten more licks or for 10 minutes (whichever occurred first). The time required for the first 100 licks and for the ten licks after CS onset were automatically recorded in tenths of a second. Estimates of lick rate obtained from these times were used as indications of fear of situational stimuli and of the CS respectively (Figs. 1 and 2).

A factorial analysis of the data on the first 100 licks (Fig. 1) of groups 2, 3, 4, and 5 yielded neither significant main effects nor a significant interaction (overall $F = .812$, d.f. $= 3/76$). Group 1 differs in lick rate from all groups at the .025 level of significance, which indicates their attenuated fear. Thus, it appears that ECS given immediately after the fear-conditioning trial (group 1) resulted in RA for the fear conditioned to situational stimuli (for example, apparatus and handling) on that trial, whereas ECS given 24 hours after the trial (groups 2 and 4) did not. This finding substantiates many published reports and is predicted by consolidation theory.

A factorial analysis of the data on lick rates from groups 2, 3, 4, and 5 after CS onset (Fig. 2) yielded a significant ECS effect ($F = 16.29$, d.f. $= 1/76$; $P < .001$), and significant interaction of ECS and CS ($F = 10.00$, d.f. $= 1/76$; $P < .005$). Individual comparisons (t-tests) between groups showed that the lick rate of group 2 was significantly greater than that of group 3 ($P < .005$), group 4 ($P < .01$), and group 5 ($P < .005$), but did not differ significantly from that of group 1. Group 1 also differed significantly in lick rate from groups 3, 4, and 5 ($P_s < .005$, .025, and .005, respectively). Groups 3 and 4 differed in lick rate at the .05-level, but neither group differed from group 5. These findings show that an ECS given 24 hours after a single CS-footshock pairing will produce RA to the CS for fear-conditioned subjects if the ECS comes immediately after a brief CS presentation. Furthermore, the degree of RA obtained in this manner is the same as that obtained when ECS comes immediately after the conditioning trial. This outcome is not predicted by consolidation theory in its present formulation. Most recent investigators of the amnesic effects of ECS have used a training-test interval of 24 hours in their experimental design (*3*), on implicit assumption that the consolidation process is completed well within this interval. However, even if the consolidation process were not completed in 24 hours, our results cannot be interpreted in terms of interference with consolidation, since ECS given 24 hours after learning did not disrupt memory processes unless it was preceded by a brief CS presentation.

The fact that group 2 had a memory loss of fear conditioned to the CS but no such loss of memory of fear conditioned to situational stimuli de-emphasizes the importance of the temporal variable in itself in the amnesic effects of ECS and raises questions about selective loss for recently acquired memory after ECS. Apparently, the primary determinant of amnesia for an event is not the "recency of memory" for the event, but the state of the corresponding memory trace at the time of ECS. In our experiment, for example, ECS given immediately after the learning event (group 1) may or may not have interfered with the long-term storage of memory for that event (*3*), or with the elaboration of memory necessary for subsequent retrieval (*4*), but it did, in either case, interfere with memory when the trace may be considered in transition, that is, in transit from active to stored memory in the first case, or in transit from one level of accessibility to another in the latter. Similarly, ECS given after reactivation of the memory trace (group 2) may be considered to produce a memory deficit by interfering with a trace in transit from stored to active memory. Thus, it appears that a primary determinant of amnesia is that the memory-trace system must be in a state of change at the time of ECS.

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