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STIMULUS ASPECTS OF AVERSIVE CONTROLS: STIMULUS GENERALIZATION OF CONDITIONED SUPPRESSION FOLLOWING DISCRIMINATION TRAINING[1]

HOWARD S. HOFFMAN[2] AND MORTON FLESHLER

PENNSYLVANIA STATE UNIVERSITY AND HOBART COLLEGE

A tone ending with unavoidable electrical shock was periodically presented to pigeons while they pecked a key for food. A second group of birds was exposed to these tone-shock contingencies and also to a second tone which never ended with shock. The gradient of stimulus generalization following training to a single stimulus was symmetrical, whereas the gradient following discrimination training was asymmetrical, but there was no evidence of peak shift. During testing, suppression to all tones gradually extinguished and in both groups the slope of the gradient increased markedly. A second experiment with the discrimination birds revealed that free shock caused a recovery of the gradient, but the asymmetry persisted.

In previous investigations, a tone ending with unavoidable electrical shock was periodically presented to pigeons while they pecked a key for food (Hoffman and Fleshler, 1961; Hoffman, Fleshler and Jensen, 1963). When pecking was completely disrupted by the tone, *i.e.* the birds had achieved the experimental criterion for conditioned suppression, shock was disconnected and the tone used in training, as well as tones of different frequencies, were presented in a random sequence. By assessing the degree to which pecking was disrupted by each of the several tones, it was possible to derive a gradient of stimulus generalization of conditioned suppression. Three major conclusions emerged: (1) conditioned suppression generalizes broadly at first, but with repeated exposure to the several stimuli (with no accompanying shock) the slope of the gradient increases; (2) the passage of time (2 years) has little, if any, effect on this process; (3) the degree to which suppression generalizes is sensitive to the level of food deprivation and to manipulation of the level of ongoing emotionality as determined by the presentation of unsignalled and inescapable shock.

During all of this earlier work, the training procedures involved the repeated presentation of a single stimulus. Hence, the results provide no information about how conditioned suppression develops during discrimination training. Nor do they provide information about the effects of such training on the gradient of stimulus generalization. Both kinds of information are necessary for a comprehensive analysis of aversive controls. The present sequence of experiments was designed to examine these processes.

EXPERIMENT I

This phase sought to establish a discrimination between a 1000 cps tone (the S_D) and a 900 cps tone (the $S\Delta$).

Method

Subjects. Six experimentally naive homing pigeons, descendants of birds originally obtained from the Army Signal Corps at Fort Monmouth, N. J., were used. They were approximately 2 yr old at the start of this research.

Apparatus. The experimental chamber and associated equipment have been fully described elsewhere (Hoffman and Fleshler, 1961). Briefly, they consisted of a Foringer pigeon chamber, equipment to program reinforcement and tones, cumulative recorders, print-out counters, and special purpose connectors (Hoffman, 1960) to deliver shock via a pair of permanently worn wing bands. Shock was generated by an Applegate constant current stimulator with shock intensity set at 1 ma. With shock at this intensity and with these *Ss*, shock stimulation yielded agitated movements,

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[2] Reprints may be obtained from Howard S. Hoffman, Department of Psychology, Burrowes Building, Pennsylvania State University, University Park, Pa.

but no evidence of tetanization. Tone frequencies were 450, 670, 900, 1000, 1100, 1500, and 2300 cps. When arranged on a logarithmic scale, the 450, 670, 1000, 1500 and 2300 cps tones lie at approximately equal intervals and the 900 and 1100 cps tones are roughly equidistant from the central tone (1000 cps). The intensity of each tone was set to a value which yielded a reading of 80 db re .0002 dynes per cm^2 on the C scale of a General Radio sound survey meter when the microphone was placed in the position typically occupied by the *S*'s head.

Procedure. All *S*s were treated alike during the several training stages which preceded the development of conditioned suppression. They were first deprived to 80% of their free feeding weight and adapted to the apparatus and to the wing bands and shock connector. They were then trained to key peck and brought to a stable performance. During this, and all subsequent phases, reinforcement consisted of a 3.5-sec exposure to the grain mixture recommended by Ferster and Skinner (1957). In developing the key peck, each *S* passed through a series of progressive steps which began with short exposures to small valued FR schedules (FR 2, FR 10, FR 30) and which terminated with extended exposure (approximately 100 hr) to the VI schedule which was to serve as the baseline for the assessment of conditioned suppression. The exposure to the FR schedules was included to generate efficient response topographies. The terminal schedule was a VI 3-min. This schedule consisted of a random sequence of 25 different intervals, generated by a special progression (Fleshler and Hoffman, 1962). With VI schedules derived from this progression, the probability of reinforcement as a function of time since reinforcement tends to remain constant. As a result, the schedule optimizes the conditions necessary for the establishment of stable response rates within the limitations imposed by the use of interval tape programmers.

When the baseline rate was stable (approximately 50 responses per min across all *S*s), the *S*s were subjected to a period of tone adaptation. This treatment had two phases: adaptation to a tone of 1000 cps and adaptation to the entire series of generalization test tones. In each of 10 sessions, a 1000 cps tone lasting 2 min was presented seven times at intervals of 10 min. In each of the next three sessions, the entire series of seven different test tones was presented. A latin square was used to equalize the distribution of stimuli within these sessions. The procedure of adapting the *S*s was employed to mitigate any suppression that might be produced by the presentation of novel stimuli (*i.e.* the test tones) during subsequent tests for stimulus generalization. It also provided a test for the stimulus generalization of adaptation. The effects of the adaptation procedures were the same as found by Hoffman and Fleshler (1961). The 1000 cps tone produced some suppression during its first few presentations, but with repeated exposure to the tone, adaptation occurred and this effect generalized completely to all of the other test stimuli. Thus, by the end of this phase, the bird's pecking behavior was very stable and unaffected by the presence of tone, regardless of frequency.

After completion of the adaptation sequences, the *S*s were randomly divided into two groups of three, and procedures to establish conditioned suppression were initiated. One group, the discrimination birds, were trained to suppress to a 1000 cps tone (the S_D) and were concurrently extinguished on suppression to a 900 cps tone (the $S\Delta$). The other group, the controls, were also trained to suppress to a 1000 cps tone, but did not receive concurrent exposure to the 900 cps tone.

For the discrimination birds, each session had the following pattern: the *S* was placed in the chamber with all lights off for at least 30 sec. The session began with the onset of lights and the establishment of the reinforcement contingencies. The first tone was presented after 10 min of pecking on the VI schedule. The tone was terminated after 2 min and 10 min later, the next tone was presented. In each session, seven tones were presented; two of these were S_Ds (1000 cps) and ended with 2 sec of shock. The other five tones were $S\Delta$s (900 cps) and were unaccompanied by shock. Ten minutes after the final tone, the lights in the chamber were extinguished and the session ended. The program of food reinforcement for key pecking was independent of the program which controlled tone and shock presentation. Thus, the *S* could achieve food reinforcement at any time during tone, during shock, or during the interval between tones. The order of tone presentations (S_D and $S\Delta$s) varied from session to session, but the following conditions were always in force: (1) the S_D was never either the first or the last stimulus, (2) the two S_Ds never occurred in sequence.

The session pattern for the control birds was identical to that of the discrimination *S*s with the exception that the 900 cps tones were never presented. Thus, both groups were exposed to the same pattern of S_Ds and shocks. These occurred in the same temporal locations within the sessions, but the control birds received no $S\Delta$s and hence no opportunity to learn the discrimination. All *S*s received 32 training sessions.

Tests for stimulus generalization were then begun. The shock circuit was disconnected and the entire series of seven tones was presented while the *S*s continued to peck at the key. During these tests, the wing bands and special connections were in place, the food was delivered on the previously established VI 3-min schedule of reinforcement, but the birds never received shock. As during the previous tone adaptation sequence, each tone lasted 2 min and the interval between tones was 10 min. The sequence of seven tones within each session was arranged by selecting successive rows from a set of latin squares. For *S*s in the discrimination group, the generalization tests were terminated after 12 sessions. For *S*s in the control group, the tests ended after six sessions.

Results and Discussion

Throughout suppression training and the subsequent tests for stimulus generalization, the base rate of pecking remained fairly stable. The average rate (estimated from the number of responses in the several 2-min intervals which preceded the onset of the 1000 cps tones) fluctuated between approximately 40 and 60 responses per min (with a mean of 52 responses per min) and there were no trends discernible throughout the various phases. The rate during the several stimuli, on the other hand, exhibited consistent reductions as a result of the aversive procedures.

The index of suppression for a given tone is expressed arithmetically as a ratio:

$$\frac{\text{Pre-tone } R\text{s} - \text{Tone } R\text{s}}{\text{Pre-tone } R\text{s}}$$

where Pre-tone Rs = the number of key pecks in the 2 min which end with tone onset and Tone Rs = the number of key pecks during the 2 min of tone.

This ratio is numerically equal to 1, when there are no Tone Rs (complete suppression); it is zero when Tone $R\text{s} =$ pre-tone Rs and it is negative when Tone $R\text{s} >$ Pre-tone Rs. This ratio serves as a partial control for variations in overall response rates within sessions, among sessions, and among *S*s. It is equivalent to measures of relative suppression used in several other experiments (Brady, 1955; Geller, 1960; Ray and Stein, 1959).

The body of Fig. 1 shows the mean suppression ratio across blocks of four sessions for the *S*s that were exposed to the S_D only (the control birds) and for those exposed to $S\Delta$s as well as S_Ds (the discrimination birds). The inset shows the data from one *S* in the discrimination group and illustrates the degree to which functions based upon group data are representative of the individual's performance.

The development of conditioned suppression to the S_D proceeded quite slowly and appears to be approaching an asymptote that is well below the potential upper limit, *i.e.* complete suppression. The acquisition function for the birds trained on the S_D only (control birds) overlaps the function for the S_D in the discrimination group. Thus, there is no indication that the exposures to $S\Delta$s during discrimination training had a substantial effect

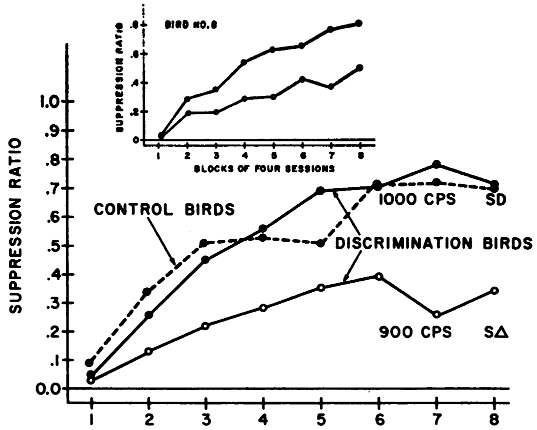

Fig. 1. The development of conditioned suppression during training to a 1000 cps tone (the control birds) and during differential reinforcement (the discrimination birds). A suppression ratio = 1.0 indicates a complete cessation of pecking during tone. A suppression ratio = 0 indicates that the rate of ongoing pecking was unaffected by the presentation of tone. The inset shows the data from one bird in the discrimination group.

on the development of suppression to the S_D. The $S\Delta$s were not, however, behaviorally neutral, for as discrimination training progressed, they exhibited an increasing capacity to produce suppression, despite the fact that they were never directly associated with shock. These data are, for the most part, consistent with expectations. Their general trends are comparable to those found in experiments involving differential reinforcement of classically conditioned responses (*e.g.* Gynther, 1957).

As Kimble (1961, p. 366) has suggested: "This result has typically occurred in studies of differential . . . conditioning and theoretically can happen under circumstances where (1) the excitatory process conditioned to S+ is greater than the inhibitory process conditioned to S—, and (2) the positive and negative stimuli are close together on the stimulus dimension."

Figure 2 shows the generalization gradients produced by the *S*s with prior discrimination training. The inset to the left shows the gradients generated by the control birds, while the inset to the right shows the gradients of the same discrimination bird whose acquisition function was shown in Fig. 1. A comparison between the initial gradients for the two groups reveals that the discrimination procedures produced a marked reduction in suppression to stimuli on the side of the gradient occupied by the $S\Delta$ (900 cps), but that these procedures had little, if any, effect on the suppression controlled by tones with frequencies at and above the frequency of the S_D (1000 cps). The effects of the discrimination training were quite permanent, for they persisted throughout the 12 sessions of testing. During these tests, the slope of the gradient progressively increased, a finding consistent with previous results (Hoffman and Fleshler, 1961; Hoffman, *et al*, 1963). Indeed, the data from the control group in the present study provide a replication of the earlier experiments.

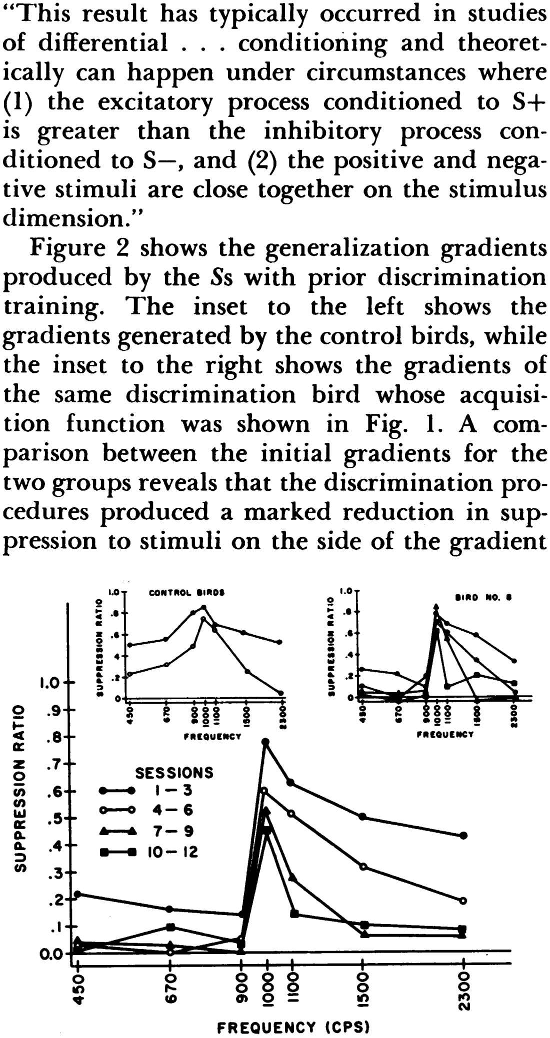

Fig. 2. The gradient of stimulus generalization after discrimination training. During training the S_D was a 1000 cps tone which ended with unavoidable shock. The $S\Delta$ was a 900 cps tone which was never accompanied by shock. The inset to the left shows the gradients for birds trained on the 1000 cps tone only. The inset to the right shows the data from one bird in the discrimination group.

Finally, when Fig. 1 and 2 are compared, it can be seen that during the initial three sessions of testing, the discrimination birds exhibited a larger difference in the levels of suppression controlled by the S_D and the $S\Delta$ than was observed during the final four sessions of training. For the most part, however, the change reflects a reduction in the level of suppression that was controlled by the $S\Delta$.

It seems probable that this effect is largely a product of the fact that the *S*s received shocks during training, but never received them during testing. As was seen in Fig. 1, the discrimination birds consistently suppressed in the presence of the $S\Delta$ even though this stimulus was never paired with shock. The finding that suppression of the $S\Delta$ showed a large reduction with the initiation of test procedures suggests that, in part, the suppression to the $S\Delta$ observed during training was being maintained by the delivery of shocks within these sessions.

The overall configuration of these data differs from the performances typically generated by comparable procedures involving appetitive controls (Hanson, 1959; Honig, Thomas and Guttman, 1959; Jenkins and Harrison, 1962). When the S_D sets the occasion for positive reinforcement, discrimination training usually leads to a relative increase in the response rate controlled by the S_D, increased slopes on both sides of the generalization gradient, and to a shift in the peak of the gradient from the S_D to some stimulus opposite to the $S\Delta$. None of these effects are visible in the present data. Instead, there is an asymmetrical gradient with many of the properties predicted by the Spence-Hull theoretical account of discrimination learning (Hull, 1952; Spence, 1936). The theory assumes that the effects of differential reinforcement are twofold. Reinforced presentations of the S_D generate a gradient of excitatory potential with a maxima at the S_D, whereas unreinforced presentations of the $S\Delta$ generate a gradient of inhibitory potential with a maxima at the $S\Delta$. According to the theory, the response tendency to a given stimulus along the gradient is a function of the combined inhibitory and excitatory potentials controlled by that stimulus. Although the generalization gradients in Fig. 2 are similar in form to theoretically predicted gradients (see p. 70, Hull, 1952), there is a discrepancy. The Spence-Hull theory predicts that discrimination training will lead to small, but consistent, reductions in the response tendency to stimuli on the side of the gradient that is opposite the $S\Delta$. The present data reveal no evidence of this effect, but the number of *S*s involved in the comparisons is small and the experiment may simply lack the requisite sensitivity.

Previous investigators working with comparable discrimination procedures involving appetitive controls have concluded that their gradients could not arise from a combination of generalized excitatory and inhibitory effects (Hanson, 1959; Honig, *et al*, 1959; Jenkins and Harrison, 1962). The present results are a product of aversive controls and while a straightforward application of the Spence-Hull theory may not provide a perfect account of these data, it is apparent that the theory does generate a number of reasonably accurate predictions.

EXPERIMENT II

By the end of the testing procedure, *S*s in the discrimination group exhibited very little suppression to tones with frequencies other than 1000 cps and the 1000 cps tone produced only a moderate degree of suppression. In short, extinction of suppression had proceeded to the point where the behavioral effects of the prior aversive experiences had been largely eliminated. In previous work, however, it was found that the extinction of suppression during testing was deceptive in that the several stimuli still possessed a latent capacity to suppress ongoing behavior (Hoffman, *et al*, 1963). When birds which had extinguished on suppression were subjected to emotional stress (in the form of unsignalled and inescapable shocks), the tendency to suppress was quickly reinstated. Moreover, for a given stimulus along the generalization gradient, the level of suppression was determined by the physical similarity between the stimulus in question and the stimulus which had been involved in the original aversive experience.

In the earlier study, the procedures for developing suppression involved the repeated presentation of the S_D only. In the present study, on the other hand, the discrimination *S*s were exposed to a large number of $S\Delta$s throughout the development of suppression to the S_D. The results of Experiment I revealed that the discrimination procedures produce a marked attenuation in the relative levels of suppression controlled by tones on the side of the gradient occupied by the $S\Delta$. Experiment II sought to determine whether or not this attenuation would persist throughout a period of emotional stress.

Method

The birds were stressed by presentation of electrical shock at various times throughout an additional series of tests for stimulus generalization. These tests were similar to those in Experiment I except that periods of darkness (TO) occurred in the interval between presentations of tone, and that a brief electrical shock was presented during each TO. Since birds do not normally peck during periods of darkness (Ferster and Skinner, 1957, p. 35) and more specifically, since the present *S*s were never observed to do so, the technique of administering shock during TOs minimized the tendency for *S*s to associate directly the shock with either the tones or the pecking behavior itself. Moreover, since the TOs with their associated shocks were programmed to be evenly distributed throughout the sessions, the relationship of tone to shock was kept uniform across tones.

The sequence of events in each session was as follows: the *S* was placed in the chamber and the lights were turned on. After 10 min of exposure to the VI 3-min schedule of food reinforcement, *S* was placed in a condition of TO. During TO the house lights and key light were turned off and reinforcement was not available. The TO lasted 2 min. Forty seconds from the beginning of the TO, *S* was administered a brief electrical shock (2 sec) at the level which had been employed during training (1 ma). Six minutes after the end of the TO, one of the seven tones was presented (without shock). As in Experiment I, the tone lasted 2 min. Two minutes following the termination of tone, another TO with associated shock occurred. This pattern was repeated until the full series of seven stimuli had been presented. Then, after 10 min the session ended. The sequence of stimuli was determined in the same manner as in Experiment I. The *S*s were run for three sessions of testing on the shock condition.

Results

Presentation of electrical shocks during TOs produced very little change in the baseline behavior. Throughout the three sessions of testing in Experiment II, the average rate during the several 2-min intervals, which ended with the onset of the 1000 cps tone, was 59 responses per min. This figure is within the extremes observed during training and testing in Experiment I (40-60 responses per min).

While the shocks did not cause a marked change in the base rate of pecking, they produced systematic recovery in the *S*s' tendency to suppress to certain of the tones. Figure 3 shows the gradient produced during the three sessions of testing under the shock conditions. For purposes of comparison, it also shows the final gradient from the previous experiment. The inset shows the data from bird 8. In addition to reinforcing the conclusion that emotional stress can amplify suppression, these results provide an answer to the question of whether or not the attenuation in suppression produced by discrimination training would persist through a period of emotional stress. It does. As seen in Fig. 3 the presentation of shocks during testing caused a recovery of the gradient, but the asymmetry found in the earlier tests is still evident. There was some tendency for bird 8 again to suppress to the 900 cps tone, but as can be seen in the group data, the other *S*s did not recover as much. Even for bird 8, suppression to the 1100 cps tone was much greater than to the 900 cps tone.

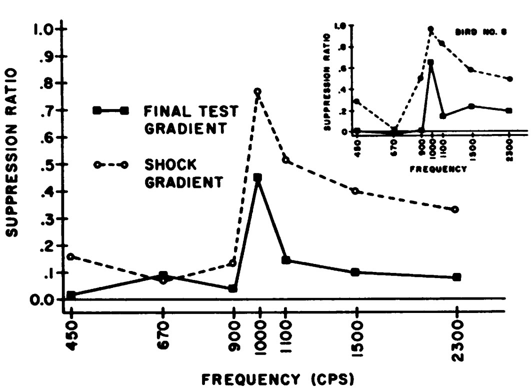

Fig. 3. The effect of free shock on the gradient produced by discrimination training. The solid line shows the final gradient from the sequence shown in Fig. 2. The dashed line shows the gradient produced when shocks were subsequently presented during the intervals between tones. The inset shows the data from bird 8.

Discussion

Previous work (Hoffman and Fleshler, 1961; Hoffman *et al*, 1963) indicated that the generalization of conditioned suppression could be reduced by either increasing the *S*'s motivation for the ongoing behavior or by repeatedly exposing *S* to stimuli along the gradient with no associated noxious event. In both cases, however, the attenuation of suppression was transient. The sharpened gradient produced by increasing the birds' motivation became broad when the motivation was subsequently reduced. And the sharpened gradient which developed as a result of extinction procedures broadened when the birds were placed under emotional stress. In the present work, a sharpened gradient (on the side occupied by the S∆) was produced by discrimination procedures during the development of conditioned suppression, but in this case the gradient remained relatively sharp when the birds were placed under emotional stress. Further research is necessary to determine how manipulation of the motivation for ongoing behavior affects the gradient established through discrimination procedures. For the time being, however, it is clear that discrimination procedures produce a profound effect on the gradient of generalization and that the effect is quite resistant to modification by emotional stress.

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