STIMULUS FACTORS IN AVERSIVE CONTROLS:
THE GENERALIZATION OF CONDITIONED SUPPRESSION¹

HOWARD S. HOFFMAN AND MORTON FLESHLER

THE PENNSYLVANIA STATE UNIVERSITY

When a previously neutral stimulus has gained control over a given segment of behavior, stimuli which are like the stimulus, but not identical to it, frequently will exhibit control over that behavior. In the present sequence of studies, we attempted to examine the phenomenon of stimulus generalization when the behavior consisted of a reduction in the rate of ongoing responses. This latter process, conditioned suppression, is one of the by-products of a training history in which a neutral stimulus has typically preceded the occurrence of an unavoidable noxious event (for example, electrical shock).

The behavior resulting from the joint action of stimulus generalization and conditioned suppression is of particular interest to the student of aversive controls because it represents a process by which the effects of aversive training may come to encompass large segments of an organism's behavior. An analysis of this process may help to clarify certain of the mechanisms involved in the behavioral phenomena of anxiety, conflict, and avoidance.

We posed three questions: (1) What is the nature of the generalization gradient following training to a single stimulus? (2) How does the gradient change during the extinction of the suppressing capacities of the several stimuli? (3) In what way does the shape of the gradient depend upon the strength of the ongoing (positively reinforced) behavior?

EXPERIMENT I: METHOD

Subjects

The Ss were four naive, domestic, White Carneaux pigeons. They were adapted to individual cages for 3 weeks and then maintained by restricted feeding at 80% of their free-feeding weights throughout the experiment. The pigeon feed was a grain combination recommended by Ferster and Skinner (1957), with a supplement of Vitamins A and D.

Apparatus

The experimental chamber was a modification of the standard Foringer pigeon box. On the front wall of the chamber were two recesses and two translucent keys. Water was continuously available in the recess on the left, whereas reinforcement was delivered through a recess below and halfway between the two keys. The right key, illuminated from behind by a red

light, was the only one used. Reinforcement consisted of a 7-second presentation of grain. During reinforcement, several events occurred: (1) The red key-light went out; (2) a solenoid-operated food tray lifted into the recess; and (3) a white light over the food tray came on. General illumination was provided by house-lights at the top of the back wall. Mounted behind this wall was a 5-inch Quam audio speaker.

Shock was administered to the pigeons via permanently fastened wing bands. Each band consisted of a length of standard chrome-plated, 0.156-inch-diameter bead chain which was wrapped twice around the base of each wing. Shock was delivered to the bird via a flexible connector fastened to the bands at the start of each experimental session. (See Hoffman, 1960, for a more detailed discussion of this method of administering shock to pigeons.) Shock of an average level of 10 volts was supplied by a Variac without external series resistance.

The pigeon chamber was housed in a large, insulated double chamber which provided 45 decibels of sound attenuation and was fitted with a one-way-vision observation port. The acoustical stimuli were generated by an RC audio oscillator (General Radio Corp., Model 1210-B). Through a system of relays, programmers, and timers, the acoustic signals were fed into the pigeon box for 48 seconds at prearranged times. The tones used in this research were spaced at approximately equal intervals along a logarithmic scale (300, 450, 670, 1000, 1500, 2250, and 3400 cycles per second), and they were equated for intensity so that each produced a reading of 80 decibels S_{pl} when the meter microphone was placed in the position typically occupied by the bird's head. During training, the oscillator was set at 1000 cycles per second, whereas during testing it was hand set to generate the frequencies listed.

Procedure

Each training session lasted approximately 2 hours and had this pattern: The pigeon was placed into the apparatus with all lights off and remained in this state for at least 30 seconds; the session was begun with the onset of lights; at the end of the session, all lights were turned off; and after a short period, the pigeon was removed. In three sessions of preliminary training, the pigeons were successively adapted to the apparatus, magazine trained, shaped to key peck, and then given 20 reinforcements under CRF. For the next two sessions, a VI 30-second schedule was used. For the rest of the experiment, the pigeons were on VI 2 minutes. The intervals of the schedule were generated by an

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arithmetic progression with a range of 1 to 239 (seconds) and an N equal to 26. After 20 sessions, the permanent wing-bands were fastened; and after the 21st session, the pigeons were always run with the connector fastened. After 15 more sessions, VI behavior was very stable. Tone adaptation was then given for 6 sessions; *i.e.*, a 48-second, 1000-cycle-per-second tone was presented without shock 10 minutes after the start of each session, and it recurred at 10-minute intervals. This operation insured that suppression occurring during the tone would be the result of its pairing with shock.

In order to mitigate suppression produced by novelty during generalization tests, the entire series of test tones was then presented without shock for 2 days. In addition to adapting out the effects of novelty, this procedure constituted a test for the generalization of adaptation. These adaptation tests consisted of the presentation of a randomized series of the seven test tones described. The interval between tones averaged 10 minutes.

Suppression training was initiated in the session following the test for generalization of adaptation. The birds were presented with a sequence of 48-second, 1000-cycle-per-second tones, and pulsing shock occurred during the final 8 seconds of each tone. Because the programming of the variable-interval schedule of food reinforcement was independent of that of the tone-shock pairings, food reinforcement could occur at any time during the tone and during the shock.

Tone-shock combinations were presented initially at widely spaced intervals (30 minutes on the average). When tone discrimination appeared sharp (high suppression during tone and normal responding after the tone), the interval between tones was reduced to about 10 minutes. When the response rate during tone was zero and the rate during nontone was normal, shock was discontinued; and without altering the schedule of positive reinforcement, the generalization tests were conducted. Each of the seven tones was presented only once during every test session, with the order in any one session determined by a row from a previously selected seven-by-seven latin square. Test sessions were continued until extinction of suppression was obtained to all but the test tone used in original training (1000 cycles per second). The procedure for one animal (Bird 20) was somewhat different. It did not receive the generalization of adaptation tests, was trained to a 95% suppression criterion, and received two test series per session.

EXPERIMENT I: RESULTS

The index of suppression used is expressed arithmetically as a ratio:

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

Pre-tone R's = the number of responses in the 40 seconds before tone onset; and
Tone R's = the number of responses during the 40 seconds of pre-shock tone.²

Observe that the ratio is one when there are no tone R's (complete suppression), that it is zero when Pre-tone R's = Tone R's, and that it is negative when Tone R's > Pre-tone R's. This ratio serves as a control for differences in over-all response rates within sessions, among sessions, and among subjects; and it is equivalent to measures of relative suppression that have been used in several other experiments (Brady, 1955; Geller, 1960; Ray & Stein, 1959).

Figure 1 illustrates a variety of degrees of suppression, with associated suppression ratios. Figures 1A and 1B, respectively, illustrate the moderate degree of

Fig. 1. Typical cumulative records taken from various points during training. The first vertical mark in each record indicates the beginning of the 40-second pre-tone period; the second indicates the onset of the 48-second tone. The broad solid mark indicates the final 8 seconds of the tone; an s appears next to this mark when shock occurs during that period. The value of the suppression ratio for each record is presented to the left of that record. (All records are from Bird 5.)

suppression obtained to the tones at the onset of tone adaptation and the lack of suppression obtained by the sixth adaptation session. Figures 1C, 1D, and 1E are samples of three progressive stages of the general course of the aversive conditioning. Record C shows the 30th tone-shock pairing. Pre-tone rate is stable and greater than tone rate. After tone-shock, responding is depressed but slowly accelerates to the pre-tone rate. Record D illustrates the effects of continued training. Behavior becomes somewhat less stable; tone suppression is increased; and behavior after tone-shock offset is markedly depressed for an extended period. Record E is an example of behavior which has reached the experimental criterion used in this study; nontone responding is relatively stable, and suppression is complete during tone.

Generalization of Adaptation

The adaptation sessions during which all test tones were presented were treated as tests of the generalization of adaptation. A Jonckheere test of ordered hypotheses for K related groups (1954) was conducted in which each side of the gradient constituted a group. The ordered hypothesis was that within a session the suppression ratios would be greatest at the extremes

²When reinforcement occurred, either during the tone or during the pre-tone period, the reinforcement time was subtracted from that period and the R's in the suppression ratio were expressed as rates, so as to correct for time spent feeding.

of the test series: $300 > 450 > 670 > 1000 < 1500 < 2250 < 3400$ cycles per second. The tests for the three Ss in the first, second, and both sessions combined were not significant. A more direct test for a generalization decrement is to compare each of the six test tones of the first session with the stimulus in the previous session that was in the same temporal position. A Welch test (Siegel, 1956) of the differences was found to be not significant. Thus, the generalization of adaptation was broad, and there was no evidence of a generalization decrement. These results do not indicate that no decrement occurs as a result of these general operations, since the number of subjects was small and the measuring procedure was not geared to adequately test such a hypothesis. Rather, it is concluded that by the end of adaptation testing, adaptation to all tones had occurred.

Generalization of Suppression

Figure 2 and 3 show the generalization gradients at several stages in the tests for Birds 5 and 9, respectively. Each gradient for Bird 5 is the average for five sessions, whereas each gradient is averaged over four sessions for Bird 9. Generalization of suppression is at first broad; and as extinction of suppression proceeds, the gradients narrow. The rate of extinction of suppression for each tone is a function of its similarity to the training tone. Through the entire test, the training tone extinguishes very little. The gradients are somewhat asymmetric, with greater generalization to the tones of lower frequencies.

For one bird (Bird 10), the signal-generating equipment had become faulty at some point during the first 15 test sessions.^a The data for these sessions were not shown, because they were atypical and were characterized by excessive variability; also, it was not possible to determine whether or not these effects were due to the signaling equipment. Thus, Bird 10 was returned to its home cage for 3 months, and testing was continued without further training. The results of this second stage of testing are presented in Fig. 4. Each gradient represents the average of four successive sessions.⁴ These gradients are sharper than those of other animals, probably because of the extinction during the early test sessions. Nevertheless, they reflect the same relationships obtained with other birds: broad generalization, sharpening with continued extinction, and a small degree of asymmetry.

The generalization gradients for Bird 20 are presented in Fig. 5. Each gradient is the result of one test session, the points being the average of the two presentations of the same stimulus in a session. The low suppression ratios of the training stimulus and

the high rate of extinction probably reflect a lower level of conditioned suppression before testing and the use of two test series per session. A comparison of Bird 20's results with the other data is confounded by the effects of the three differences in treatment: no test-stimulus adaptation, a lower terminal suppression ratio, and double-series test sessions. In spite of these differences, Bird 20's data confirm the general trends found in the other animals: broad generalization, sharpening of the gradients in extinction, and greater generalization to the lower test tones.

EXPERIMENT 1: DISCUSSION

The results of any measurement of stimulus generalization is a function of the training and testing procedures used. Furthermore, under constant conditions of training and testing, the gradient of generalization reflects the investigator's choice of scales for both the stimulus and response dimensions. It is commonly believed that the stimulus dimension should represent psychological or sensory units of equal magnitude. To date, no such scale has been developed for pigeons along an auditory dimension, and, furthermore, no data are available on auditory frequency or intensity discriminability for this species. Audiograms, the only data available, indicate small differences in sensitivity over the range of stimuli used in the present research. Faced with this problem, Jenkins and Harrison (1960) used the log frequency scale to assess the generalization gradient for food-reinforced responses. In doing so, they assumed that the discriminability function for the pigeon was probably not very different from that of the human (since their audiograms are similar). Their assumption seemed justified because they found no evidence of asymmetry in their gradients. These same test frequencies were used in the present research; however, the gradients reported here are somewhat asymmetric. Questions as to the proper scale of discriminability must await further research dealing directly with frequency discriminability and iso-intensity contours. For now, it should be emphasized that in the present research the asymmetry was small and did not obscure the general shape of the gradients.

The response index used in this study is of more concern. The suppression ratio is a direct, simple measure of relative performance decrement. However, measurement by relative suppression presupposes that the CS will produce the same relative decrement independent of the rate of responding at the moment of the CS presentation. The validity of this assumption has not been assessed. A second factor of importance is that at some constant level of ongoing behavior, the suppression ratio is sensitive to only a particular range of variation in the suppressing ability of a stimulus. The ratio has a lower threshold at .00 and a maximum at complete suppression; beyond both of these, it does not vary with the suppressing ability of a stimulus. Within that range, the scale that best characterizes variation in the suppressing ability of a stim-

^aSince only Bird 10 was being tested at the time of the equipment failure, the data for the other animals were unaffected by the faulty equipment.

⁴Between the fourth and fifth sessions of Bird 10's testing, 3 weeks intervened. This operation produced no apparent change in the pattern of Bird 10's results.

Fig. 2. Generalization gradients for Bird 5. The numbers to the left of each gradient indicate the sessions included.

Fig. 3. Generalization gradients for Bird 9. The numbers to the left of each gradient indicate the sessions included.

Fig. 4. Generalization gradients for Bird 10. The numbers to the left of each gradient indicate the sessions included.

Fig. 5. Generalization gradients for Bird 20. The numbers to the left of each gradient indicate the sessions included.

ulus is at present unknown; and the same scale might not be adequate for different levels of ongoing behavior. Additional research is needed to reveal these scales.

Although the training criterion used in this study set a minimum suppression level at 100% rather than a range, it did not limit the degree to which a bird had gone beyond this minimum. In the initial tests, several test stimuli produced complete suppression, a result which provides no information about the shape of the initial gradient of generalization. What is clear is that initial generalization was broad and subsequent extinction was slow. It should be recalled that all of the tests for generalization were conducted without shock. Therefore, any changes in the shape of the gradient during testing must reflect differences in the extinction of the suppressing capacity of the several stimuli. Because the broad gradients systematically narrowed as testing continued, it must be concluded that there were differences in the rate of extinction of the behavioral control exercised by the several stimuli, a finding which is consistent with the results of several other investigators (Hovland, 1937a, 1937b, 1937c; Littman, 1949; Wickens, Shroder, & Snide, 1954; Brown, 1942; Jenkins & Harrison, 1960).

This sharpening of the gradient of generalization with extinction is a peculiar effect in that it seems to represent the development of discriminated behavior without either previous or concurrent differential reinforcement. Such sharpening might be expected if there were differences in the equation form of the extinction functions for the several stimuli. In general, however, the postulation of such differences would form a relatively unpalatable addition to the several

theoretical treatments of generalization, because it would greatly complicate these theories and thus tend to reduce their value as conceptual models. Fortunately, an alternative and far simpler process can be postulated to account for these effects. The generalization gradient can sharpen during extinction if the extinction curve is initially convex and if the several stimuli exercised different degrees of stimulus control at the start of testing. Brady (1955) found that the extinction curve for suppression was in fact initially convex when the ongoing behavior was maintained on a VI schedule, and the results of the present study (as in Fig. 2-5) also suggest convexity. More direct evidence of such convexity appears in Fig. 6. This figure shows the extinction of suppression for a bird (Bird 22) that received the same training as the other birds but was extinguished on the 1000-cycle-per-second tone without prior tests for stimulus generalization. During each session, seven tones were presented; and each point in the figure represents the mean suppression ratio per session. Clearly, the tone lost its capacity to suppress very slowly, and the curve representing the extinction of suppression was initially convex. In view of these data, the question then becomes: Can the extinction curves for the various tones be derived from one convex extinction function, when the only difference among the tones is the amount of initial suppression and not a difference in the rate of extinction (slope of the curve)? The crucial evidence on which to evaluate this question derives from the comparison of the extinction curves of the training tone and the test tone in the same range of suppression. Unfortunately, the degree to which the extinction curve for the training tone overlapped with that of the test

Fig. 6. Extinction of suppression to the 1000-cycle-per-second tone for Bird 22.

tones was small since testing was ended at test-tone extinction; consequently, the question must be left open for now.

In general, the present findings are consistent with the results of the one previous study of the generalization of conditioned suppression (Ray & Stein, 1959). In that experiment, discrimination training caused rats to suppress bar presses to an 1800-cycle-per-second tone but not to a 200-cycle-per-second tone. Tones with frequencies intermediate between these two extremes were found to cause intermediate degrees of suppression. Although procedural differences between their study and the present one (different organisms, the use of shock during testing, different stimuli on different scales of stimulus discriminability, to mention a few) are sufficient to preclude detailed comparisons, their gradients do appear sharper than those reported here. Since sharpened gradients are the expected effect of discrimination training, their results are generally in accord with the present findings.

EXPERIMENT II:

THE EFFECT OF DEPRIVATION LEVEL

The conclusion that conditioned suppression varies as an inverse function of the strength of ongoing posi-

tively reinforced behavior has been verified in several studies (Estes & Skinner, 1941; Brady, 1955; Goy & Hunt, 1953; Geller, 1960). In Experiment II, we attempted to investigate the effect of this variable on the generalization of conditioned suppression.

Procedure

Two experimentally naive White Carneaux pigeons were subjected to the same sequence of operations as that used in Experiment I. Toward the end of suppression training, however, their body weights were reduced slowly from 80% to 70%. Upon reaching the suppression criterion, shock was discontinued permanently and testing was begun. After several sessions (three for Bird 11 and four for Bird 21), testing was interrupted for 2 weeks, during which time the birds' body weights were increased to 80%. Without further training and with no further shocks, testing was resumed until the tendency to generalize was small.

EXPERIMENT II: RESULTS

The results of Bird 11 are presented in Fig. 7. The upper graph shows the gradients at the two different levels of body weight, and the lower one shows the

Fig. 7. Generalization gradients for Bird 11. The upper graph presents the gradient at 70% body weight and the initial gradient at 80% body weight. The lower graph presents the gradients during continued testing at 80% body weight (with the initial 80% gradient repeated). The numbers to the left of each gradient indicate the sessions included.

Fig. 8. Generalization gradients for Bird 21. The upper graph presents the gradient at 70% body weight and the initial gradient at 80% body weight. The lower graph presents the gradients obtained during continued testing at 80% body weight (with the initial 80% gradient repeated). The numbers to the left of each gradient indicate the sessions included.

continued performance at 80% body weight. The 70% body-weight gradient is extremely sharp, showing almost no generalization. The first gradient produced after the body-weight increase is much broader. It should be recalled that the 70% gradient represents the mean value for the first three sessions, whereas the 80% gradient is for Sessions 4-6, and that no shock occurred once testing had begun. The lower graph shows that with continued testing at 80%, the gradient slowly sharpens in a manner similar to that of the birds tested solely at 80% body weight.

A similar graph is presented for Bird 21 in Fig. 8, and the same trends appear: sharp initial gradients at 70% body weight; a much broader gradient after the increase in weight; and slow, subsequent extinction of suppression at 80% body weight.

In this experiment, the effects of the body-weight change are confounded with the effects of the interpolated period. However, the results of Bird 10 can provide some information about the effect of interpolated time, since 3 weeks passed between the fourth and fifth test sessions. As Fig. 4 shows, the effect of interpolated time did not change the general course of the gradient in extinction; *i.e.*, the gradients successively sharpened. Since the broadening of the gradients with increased body weight is in a direction opposite to that which would be expected from continued extinction and from interpolated time, it may be concluded that the degree to which suppression generalizes is an inverse function of the motivation for the ongoing, positively reinforced, behavior.

One effect of the changed deprivation level was a modification of the over-all rate of responding. The magnitude of this effect can be estimated by averaging the response rates during the pre-tone periods of test sessions conducted under the two different deprivation levels. For Bird 21, the average pre-tone response rate during test sessions 1-4 (70% free-feeding weight) was 110 responses per minute; however, during Sessions 5-8 (80% free-feeding weight), the bird's average rate was 55 responses per minute. For Bird 11, the pre-tone rates during the comparable periods of testing were 134 and 103 responses per minute, respectively. For both birds, the differences are statistically significant ($P < .01$ for each). These rate differences may be compared to the relatively stable average rates of 102 and 103 responses per minute observed before and after the interpolated 3-week period of Bird 10 when its body weight remained constant at 80%. In general, the results of this analysis are consistent with those of several other studies (Clark, 1959) in which VI rate was found to be an inverse function of percentage body weight.

Because response rate changed with the modification in the percentage body weight, it cannot be determined whether motivation level or its effects on response rate produced the change in the generalization gradient. Regardless of which factor is responsible for this change, however, the results of Experiment II indicate that the generalization of suppression is deter-

mined in part by variables which control the ongoing behavior, and that manipulation of these variables can profoundly influence the magnitude of such generalization.

SUMMARY

Pigeons pecking for food on a variable-interval schedule were periodically presented with a 48-second tone which ended with 8 seconds of unavoidable shock. When the initial 40 seconds of tone caused stable, complete suppression, shock was discontinued, and tones were presented with frequencies above, below, and including that of the training tone. At first, suppression generalized broadly; but with continued tests, the gradient narrowed until only the training tone caused suppression. A second portion of the study revealed that the degree to which suppression generalizes decreases as motivation for the positively reinforced ongoing behavior increases.

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