*STIMULUS FACTORS IN AVERSIVE CONTROLS:
CONDITIONED SUPPRESSION AFTER EQUAL
TRAINING TO TWO STIMULI¹*

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Pigeons trained to peck a key for food were periodically presented with tones ending with electrical shock until tone presentation consistently suppressed ongoing pecks. Shock was then discontinued and gradients of stimulus generalization were assessed by presenting tones with frequencies above, below, and at the frequencies of those used to develop conditioned suppression. When the training tones had frequencies at 670 and 1500 cps, resulting gradients were bi-modal with peak suppression at 670 and 1500 cps. Of the other test tones, 1000 cps produced the most suppression. When the training tones had frequencies at 450 and 2250 cps, bi-modal gradients were again obtained with peak suppression to the 450 and 2250 cps tones. Of the other test tones, 1000 cps produced the least suppression. These results support the hypothesis that generalized response tendencies summate.

In previous studies (Hoffman and Fleshler, 1961; Hoffman, Fleshler, and Jensen, 1963), pigeons trained to peck a key for food were periodically presented with a 1000 cps tone which ended with electrical shock. When tone presentation consistently reduced the rate of ongoing key pecks (conditioned suppression), shock was discontinued and gradients of stimulus generalization were obtained by presenting tones with frequencies below, at, and above 1000 cps while subjects continued to peck the key for food.

The present investigation differs from the earlier work in that training involved presentation of two tones (having different frequencies), both of which ended with electrical shock. In addition to its implications for the interpretation of aversive controls, the investigation of stimulus generalization after training to two stimuli is relevant to the theoretical issue of summation in stimulus generalization.

When interpreted in the present context, the summation hypothesis (Hull, 1943) holds that the gradient of stimulus generalization that results from training to two stimuli rep-

resents an interactive sum of the gradients produced by training to each stimulus separately. Thus, at points along the stimulus continuum where the separate gradients overlap, the stimuli have two sources of generalized response tendency. The summation hypothesis asserts that these tendencies interact to produce a combined response tendency which is greater than either one alone. The main alternative to the summation hypothesis is that when a stimulus has two sources of generalized response tendency the resulting tendency is equal to that of the stronger one alone.

Past investigations of the generalization gradient after training to two stimuli have employed positive reinforcement and have failed to confirm or deny either of these alternatives (Kalish and Guttman, 1957). The present investigation differs from the above primarily in its focus on aversive procedures. Here the question of summation was evaluated by assessing the relative level of conditioned suppression to the tone which lies midway between the tones used in training. According to the summation hypothesis, when the tones used in training are close to each other the gradients around each of them would be expected to overlap in the middle. As a result, suppression to the tone midway between them should be elevated relative to the suppression controlled by tones that are equally remote from the training tones but are located in parts of the stimulus continuum where the gradients do not overlap. When, however, the

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tones used in training are more widely separated, the overlap of the separate gradients would be either reduced or eliminated. As a result, suppression to the tone midway between the training tones should be relatively reduced.

METHOD

Subjects

Six experimentally naive homing pigeons, descendants of birds originally obtained from the Army Signal Corps at Fort Monmouth, New Jersey, were used. They were approximately 3 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, printout 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 between 1.5 and 3.5 ma such that for a given subject shock yielded agitated movements, but no evidence of tetanization. Tone frequencies were 300, 450, 670, 1000, 2250, and 3400 cps. When arranged on a logarithmic scale, these frequencies lie at approximately equal intervals and, as suggested by Jenkins and Harrison (1960), the differences among adjacent pairs are probably equally discriminable. Tones were equated for intensity so that each produced a reading of 80 db spl on the C scale of a General Radio sound survey meter when the microphone was placed in the position typically occupied by the bird's head.

Procedure

The subjects were first deprived to 80% of free feeding body weight and adapted to the apparatus and to the wing bands and shock connector. In developing the baseline behavior, each subject passed through a series of progressive steps which began with short exposure to small-valued variable-interval schedules (VI-10 sec, VI-30 sec, VI-60 sec) and terminated with extended exposure (approximately 100 hr) to a VI-3 min schedule. The

VI-3 min schedule, which served as the baseline for assessing conditioned suppression, consisted of a random series of 25 different intervals, generated by a special progression (Fleshler and Hoffman, 1962). With VI schedules thus derived, the probability of reinforcement as a function of time since reinforcement tends to remain constant. As a result, the schedule optimizes the conditions necessary to establish 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), the birds were subjected to four sessions of tone adaptation. In each session of adaptation, all seven tones were presented, with the sequence varying from day to day. Each tone had a duration of 2 min with a 10 min interval of silence between them. The procedure of adaptation 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. By the end of adaptation, pecking response was very stable and was unaffected by the presentation of tone, regardless of frequency.

Upon completion of the adaptation procedure, suppression training was begun. Suppression training consisted of pairing tones with shock and presenting each tone-shock pair three times during a session. For the three birds of Group I, tone frequencies were 670 and 1500 cps; for the three birds of Group II, 450 and 2250 cps. With this arrangement, a training session consisted of six tone-shock pairings ordered so that neither tone was presented more than twice in a row, and between sessions orderings which had each session begin and/or end with a different tone from the previous session. Each training session lasted approximately 80 min and had the following pattern: the pigeon was placed in the apparatus with all lights off and remained so for at least 30 sec. The session started with the onset of the lights in the box. The bird was then given a 10-min period in which to develop a stable rate of pecking after which the first tone was presented. Each tone lasted for 122 sec with shock administered during the final 2 sec of tone. As in the previous phases of this experiment, the time between tones was 10 min.

Tests for stimulus generalization involved

procedures identical to those used in adaptation. All seven tones were presented without shock and in random order. Each test session lasted approximately 80 min with the interval between tones again 10 min. Both groups initially received 28 sessions of suppression training. Subjects trained on 670 and 1500 cps tones then received 20 test sessions. Subjects trained on 450 and 2250 cps tones received eight test sessions, but, since the gradients were not sufficiently uniform, testing was stopped and suppression training procedures were readministered for 12 sessions. After retraining, testing procedures were again instituted for 12 sessions.

RESULTS

Figures 1 and 2 show the gradients of stimulus generalization of conditioned suppression for the 20 test sessions of Group I and the 12 test sessions following retraining for Group II. In both figures, the index of suppression for a given tone is expressed arithmetically as a ratio:

$$\frac{\text{Pre-tone Rs} - \text{Tone Rs}}{\text{Pre-tone Rs}}$$

where Pre-tone Rs equal the number of key pecks in the 2-min period which ends with

Fig. 1. Stimulus generalization gradients after suppression training to 670 and 1500 cps tones. Each gradient represents data averaged across four test sessions and the sequence of gradients show successive blocks of sessions in descending order. The larger curves are based on the data from all three subjects; the inset shows the data from a single subject, Bird No. 39.

Fig. 2. Stimulus generalization gradients after suppression training to 450 and 2250 cps tones. Each gradient represents data averaged across four test sessions and the sequence of gradients show successive blocks of sessions in descending order. The larger curves are based on the data from all three subjects; the inset shows the data from a single subject, Bird No. 42.

tone onset and Tone Rs equal the number of key pecks during the 2 min of tone. This ratio is numerically equal to one when there are no tone responses, *i.e.*, complete suppression; it is zero when Tone Rs are equal to Pre-tone Rs; it is negative when the number of Tone Rs exceeds the number of Pre-tone Rs.

The larger functions in Fig. 1 and 2 show successive gradients (in descending order) across blocks of four test sessions. The insets show the data from one subject in each group.

Figure 1 reveals an initial broad gradient. As testing proceeded, suppression to the several tones gradually extinguished. In general, however, suppression to tones on the wings of the gradient extinguished more rapidly than suppression to both the tones used in training and the tone which lies midway between them. Figure 2 also shows gradients which decline as suppression extinguishes, but differences in rates of extinction among the several tones are not clear.

As seen in Fig. 1, peak suppression occurs to the 670 and 1500 cps tones, and suppression to the 1000 cps tone, which was the test tone intermediate between the two training tones, was typically higher than to the two test tones which are also one step removed from the training tones but on opposite sides of the gradient. A Wilcoxon matched-pairs signed-ranks test was employed to assess this effect

statistically. The suppression ratios to the 450 and 2250 cps tones were averaged for each session and compared to the 1000 cps tone on a session-by-session basis for the first 16 sessions. Individual tests revealed that the observed heightened suppression to the 1000 cps tone is highly significant (Bird No. 37: $n = 16$, $T = 14.5$, $p < .01$; Bird No. 38: $n = 15$, $T = 17.5$, $p < .01$; Bird No. 42: $n = 15$, $T = 4$, $p < .01$).

Figure 2 provides an altogether different picture. Here, peak suppression occurs to the 450 and 2250 cps tones, and, in contrast to the data of Fig. 1, the 1000 cps tone produced the least amount of suppression of all the other test tones. A Wilcoxon test was again employed to assess this effect. The suppression ratios to the 300, 670, 1500, and 3400 cps tones were averaged for each session and compared to the 1000 cps tone on a session-by-session basis. The 1000 cps tone was found to be significantly lower than the mean of the other four test tones for two of the subjects (Bird No. 39: $n = 7$, $T = 0$, $p < .02$; Bird No. 44: $n = 6$, $T = 0$, $p < .05$), but not for the third (Bird No. 40: $n = 8$, $T = 26$, $p > .05$).

DISCUSSION

The relatively flat gradients in Fig. 2 are similar to those obtained in the initial tests with these subjects (see the procedure section), but they are more uniform. Apparently when pigeons are trained to suppress to two dissimilar stimuli there is a relative weakening of the differential control exercised by other stimuli along the same continuum.

As applied to the present study, the summation hypothesis predicts that, when training involves tones with similar frequencies, the test tone intermediate between the training tones will exhibit more suppression than test tones which are also one step removed but on opposite sides of the gradient. When, however, training involves tones that are widely spaced on the stimulus continuum, little or no summation should occur, and the tone intermediate between the training tones should exhibit less suppression than other test tones. As seen in Fig. 1 and 2, both of these effects occurred. Indeed, in the initial gradient of Fig. 1 the 1000 cps tone exhibited even more suppression than either of the tones used in training.

Although this latter finding is in close ac-

cord with predictions based on the summation hypothesis, it does not, in and of itself, provide an unequivocal answer to the question of whether or not summation actually occurred. To demonstrate summation unequivocally, it must also be shown that in Fig. 1, suppression to the 1000 cps tone is greater than would have occurred had subjects been trained on either 670 or 1500 cps alone. That is, it must be shown that the generalization gradients around both 1500 and 670 cps are not asymmetrical with heightened suppression occurring in the region of 1000 cps. Although a laboratory analysis of this issue is obviously possible, several indirect lines of evidence suggest that asymmetrical gradients with heightened suppression at or near 1000 cps are most unlikely.

First, as seen in Fig. 2, when training involved more widely separated tones (450 and 2250 cps), suppression to the 1000 cps tone was lower than to any other tone. This would not be expected if the birds were especially likely to suppress to tones with frequencies that approximate 1000 cps. Second, at equal levels of suppression to the tone paired with shock the slope of the generalization gradients for birds trained at 1000 cps only are almost identical to the slopes at the extremes of the gradients in Fig. 1 (see Hoffman *et al.*, 1963). Third, it is unlikely that the tones with frequencies near 1000 cps are differentially loud, since the tones were equated for intensity (80 db) and, at intensities this high, the equal loudness contour is almost certainly quite flat. Finally, Jenkins and Harrison (1960) investigated auditory stimulus generalization using positive reinforcement only and found no evidence of asymmetrical gradients after training to either 1000 cps or to 450 and 2500 cps. Indeed, the gradients around 1000 cps were almost identical to the gradients around 450 and 2500 cps. In short, all of the available data point to the notion that training at stimuli other than 1000 cps is not especially likely to produce an asymmetrical generalization gradient. Hence, it is reasonable to conclude that the present finding of heightened suppression at 1000 cps (in Fig. 1) reflects the summation of generalized conditioned suppression tendencies.

When Kalish and Guttman (1957) used positive reinforcement procedures to examine the gradient of stimulus generalization after equal

training to two stimuli, their data exhibited conspicuous (and statistically reliable) departures from the quantitative predictions derived from both the summation and the non-summation hypotheses; for this reason, both hypotheses were rejected. Examination of their gradients, however, reveals that in every case the departures from the gradients predicted by the nonsummation hypothesis are in the direction predicted by the summation hypothesis. That is, the nonsummation hypothesis was rejected because the response tendency in the region where the separate gradients overlapped was greater than the response tendency expected from either gradient alone. The departures from the predictions based on the summation hypothesis, on the other hand, occurred in both directions and in two of the three cases these departures were in the direction of a greater, rather than a lesser, response tendency. Thus, the summation hypothesis was rejected largely because the empirical gradients exhibited an even greater summation effect than predicted by the derived theoretical function. These considerations suggest that, although the predictions derived by Kalish and Guttman are untenable, the principle of summation nonetheless received strong support. That principle requires only that overlapping gradients produce a combined response tendency greater than the response tendency expected from either gradient alone. This is

what Kalish and Guttman found.

The present study involved aversive procedures, but its findings are almost identical to those of Kalish and Guttman. Suppression in the region of the stimulus continuum where the separate gradients overlap is greater than the suppression expected from either gradient alone. Since these findings agree with the basic contention of the summation hypothesis, it is concluded that the present study provides support for the principle of summation.

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