DIFFERENTIAL RESPONDING AS A FUNCTION OF AUDITORY STIMULUS INTENSITY WITHOUT DIFFERENTIAL REINFORCEMENT¹

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Two groups of four rats each were trained to bar press on a variable-interval 2-min schedule. During training, either 3, 5, or 9 auditory stimuli of various intensities were randomly presented. A direct relationship between stimulus intensity and rate of responding was obtained, but it was more consistent in the group trained initially with three stimuli than for the group that started with nine stimuli. The results are related to the concept of stimulus intensity dynamism and the necessary conditions for the acquisition of stimulus control.

The following report is concerned with two issues: (1) the relationship between stimulus intensity and the rate of emission of an operant lever-pressing response; and (2) the relationship between differential reinforcement and the acquisition of stimulus control.

An earlier study (Hegge, Pierrel, Sherman, and Sadowsky, 1965) reported that when rats were exposed to a range of nine auditory stimulus intensities (60 to 100 db in 5-db steps) of a 4-kHz tone, no rate-modulating effect, either facilitative or suppressive, was measured when lever-pressing was reinforced equally often in the presence of each intensity. It was concluded that the absence of a differential reinforcement procedure precluded the development of stimulus control, and therefore the auditory intensities were not part of the effective stimuli that maintained lever pressing.

We have also observed (Pierrel, Sherman, Blue, and Hegge, 1970) however, that rats exposed to only three intensities of a 4-kHz tone (60, 80, 100 db) under conditions of non-differential reinforcement emitted responses at rates correlated with the auditory stimulus intensity. This would indicate that a dynamism effect is not dependent upon establishing

the intensities as discriminative stimuli.

The data reported below extend the work of Hegge *et al.* (1965), and Pierrel, *et al.* (1970), which might seem to be at variance. These findings also broaden the issue of the necessary and sufficient conditions for the acquisition of stimulus control.

METHOD

Subjects

Eight male albino rats of a Sprague-Dawley derived strain were purchased from Carworth, Inc.; all animals were 100 to 120 days old at the start of experimentation.

The animals were randomly assigned to one of two groups, and free-feeding weights were determined. They were then reduced to 80% of these weights, and maintained at or near this level by food reinforcement during experimental hours. Water was present at all times in the home and experimental cages.

Apparatus

Four similar sound-shielded shock-mounted 12.8 cubic ft refrigerator shells were partitioned into animal and equipment sections using Fiberglas board covered with Fiberglas cloth. The animal enclosure was an acoustically transparent cage 5 by 8 by 5.75 in. (12.7 by 20.3 by 14.6 cm) constructed of stainless steel rods mounted in a Lucite frame. A high-frequency speaker was centered 7.5 in. (19.1 cm) above it.

The equipment section contained a motor-

¹This research was conducted as part of a research program being carried out under United States Public Health Service Grant HD-00928. Reprints may be obtained from Rosemary Pierrel, Walter S. Hunter Laboratory of Psychology, Brown University, Providence, Rhode Island 02912.

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driven retractable lever and pellet dispenser. The bar was calibrated to operate a micro-switch upon the application of a 3-g weight. The units were provided with continuous air circulation by way of a sound-silenced ventilation system.

Within the enclosures, the background level of noise in the mid-range frequencies was approximately 28 to 30 db in the absence of auditory stimulus input. With a 4-kHz tone present, a uniform sound field was produced with point-to-point intensity differences not exceeding 2 db. All sound intensities specified in this study are in terms of a 0-db reference level of 20 microneutons/m² (0.0002 microbar). A General Radio Sound Level Meter, Model 1551 B, set to its "A" weighting scale, was used for all calibration procedures.

The system that produced the sound stimuli included an audio oscillator; a preamplifier, specially constructed to provide a smooth attack and decay of the signal upon the operation of internal relay circuitry; a bank of fixed attenuators, any one of which could be operated by a stepping switch; and four individually calibrated 2-w distribution amplifiers, each connected to a single speaker in one of the experimental chambers. The intensities were presented as pulsing tones with a repetitive sequence of 1.5 sec on and 2.5 sec off. All intensity changes were arranged to occur when the tone was off.

All control and recording functions were performed by conventional relay circuitry located in a room adjacent to the experimental room.

Procedure

The two groups of four animals each were run successively. For both groups, on the first day the animals were placed in the experimental chambers and trained to press the bar. Group II was bar trained with an imposed auditory stimulus of 80 db. Because of an apparatus failure, there was no imposed auditory stimulus present during the bar training session for Group I. There were 50 reinforcements (45 mg P. J. Noyes Pellets) on a fixed-interval 10-sec schedule and then the schedule was changed to the variable-interval 2-min schedule that was to be in effect constantly during subsequent sessions. After another 75 to 80 reinforcements on this schedule, the animals were returned to their home cages.

Non-differential training began the afternoon following bar training for each group. All sessions were 4 hr in duration, with two sessions scheduled each day from 12 noon to 4 p.m. and 12 midnight to 4 a.m. Between sessions, the animals remained in the experimental chambers. The sound was turned off and the bars retracted. During the experimental hours, the subjects received their entire food ration in the form of reinforcers.

Group I was exposed to an alternation of three stimuli, 60, 80, and 100 db for 12 consecutive sessions. They were then presented with five stimuli, 60, 70, 80, 90, and 100 db for 10 sessions, following which they were exposed to nine stimuli between 60 and 100 db (in 5-db steps) for 10 more sessions. Finally, they were returned to the original three-stimulus condition for two sessions.

Group II was presented with two of the same stimulus sequences in a different order. This group was started with the nine-stimulus sequence and run for eight sessions. They were then switched to the three-stimulus condition for 40 sessions, and finally were trained for 80 hr on a discrimination between 60 db (reinforcement stimulus) and 100 db (no reinforcement).

All stimulus sequences were designed to minimize obvious sequential dependencies. Auditory intensity increments and decrements of various magnitudes were balanced and extended sequences containing only increments or decrements were avoided. Each stimulus was presented for an equal amount of time within each hour in the three and five stimulus conditions (20 min each for the former, 12 for the latter) in periods of 1, 2, or 3 min each. For the nine-stimulus condition, 60, 80, and 100 were presented for 8 min each hour, and the other six stimuli appeared for only 6 min per hour (again in 1, 2, or 3 min segments). For details of the two-stimulus, differential reinforcement procedure see Pierrel *et al.* (1970).

For both groups, the mean interreinforcement interval was 2 min, and the sequence of intervals was obtained by randomizing the terms of a geometric progression.

RESULTS

The data for the four stages of Group I appear in Fig. 1 a and b. In the first stage,

Group I was exposed to 60, 80, and 100 db for 12 sessions. The response rate per minute as a function of stimulus intensity for each of the four animals during all 12 sessions is shown in the left half of Fig. 1a. A direct linear relationship between response rate and stimulus intensity was obtained for each animal except Rat 2 (broken line), whose function is essentially flat. For Rats 1, 3, and 4, this rate-intensity relationship appeared during the first or second session, and remained quite consistent for all succeeding 4-hr periods. A similar set of conditions has been employed with two more groups of four rats each. (See the "special group" in Pierrel *et al.*, 1970.) Seven of the eight animals in these groups also developed a consistent monotonic increase in response rate as a function of stimulus intensity.

Two more stimuli were added (70 and 90

db) after the twelfth session, and the data for the 10 sessions with five stimuli are shown in the right half of Fig. 1a. The stimulus intensity-response rate relationship was maintained, with some indication of a change from a linear to a positively accelerated function. Again only Rat 2 failed to show the effect. The data for the 10 sessions with nine stimuli are presented in the left half of Fig. 1b. More variability can be noted, but the overall shape of the curves for Rats 1, 3, and 4 has clearly become positively accelerated. The right half of Fig. 1b presents the data for the two sessions in which only 60, 80, and 100 db were again presented. The positive acceleration that appeared with the exposure to five stimuli is retained, and the effect is increased over that of the first 12 sessions. The mean for all four animals for 60 db during the first stage was 14.9 responses per minute and for 100 db

Fig. 1a. Left half: responses per minute as a function of stimulus intensity for the three-stimulus condition. Each point on each function is the mean over 12 sessions. Right half: responses per minute as a function of stimulus intensity for the five-stimulus condition. Each point on each function is the mean over 10 sessions.

Fig. 1b. Left half: responses per minute as a function of stimulus intensity for the nine-stimulus condition. Each point on each function is the mean over 10 sessions. Right half: responses per minute as a function of stimulus intensity during the return to the three-stimulus condition. Each point on each function is the mean over two sessions.

it was 17.3. During the last stage these means were 12.2 and 18.5 respectively.

Group II was exposed initially to the nine-stimulus condition. The data for the eight sessions of this training are shown in Fig. 2a. The curves for Rat 6 and 9 display a degree of the stimulus intensity-response rate relationship seen for Group I, but the effect is smaller, while Rat 7 and 8 produced flat functions.

Training on the nine-stimulus condition was terminated after eight sessions because the curves were becoming flatter rather than increasing in slope as was the case in Group I. This effect can be seen in the left half of Fig. 2b. The solid line presents the mean for Sessions 1 through 3. The rate-intensity relationship is apparent with elevated responding to 95 and 100 db. However, over the last three sessions (broken line), the responses appear to

be randomly distributed across intensity. A shift to the three-stimulus condition was made with the hope that a clearer rate-intensity relationship would be produced. This did not occur. The effect appeared and disappeared over sessions for various of the animals in an unstable fashion, as can be seen in the right half of Fig. 2b. The mean for the first five sessions (9 to 13) with three stimuli presented is plotted with the solid line. A monotonic increasing relationship appears similar to that seen in the left half of Fig. 1a. Representative segments of sessions from the middle (26 to 30) and end (44 to 48) of training indicate that the rate-intensity relationship is not maintained.

In an attempt to determine whether these animals could be brought under stable control by auditory stimuli, Group II was ex-

Fig. 2a. Responses per minute as a function of stimulus intensity for the nine-stimulus condition. Each point on each function is the mean over eight sessions.

Fig. 2b. Left half: mean responses per minute as a function of stimulus intensity for the first three sessions (solid line) and last three sessions (broken line) of the nine-stimulus condition. Right half: mean responses per minute as a function of stimulus intensity for the first five (solid line), middle five (broken line), and last five (dot-dash line) sessions on the three-stimulus condition.

posed to a differential reinforcement situation with only two stimuli. In the presence of 60 db, reinforcement was available on the VI 2-min schedule; with 100 db present, no reinforcement was available (extinction). All four subjects developed differential responding over the 80 hr of training, but at a much slower rate than for comparable groups trained with those two stimuli, given no prior non-differential exposure to the various auditory intensities. For example, Group 60-100 in Pierrel *et al.* (1970) emitted 91% of their total responding with a range of 87 to 94% in the presence of the positive stimulus after 80 hr of training. The present group mean was only 72% with a range of 59 to 83%.

DISCUSSION

In his revised set of postulates, Hull introduced the concept of "stimulus intensity dy-

namism". The issues surrounding this concept, some of its history and present status have been discussed in detail elsewhere (Pierrel *et al.*, 1970; pp. 32-33). The basic empirical content of the dynamism notion is that a direct relationship exists between the magnitude of an effective stimulus and the strength of the response that is being measured.

Our earlier failure to find this result (Hegge *et al.*, 1965) now appears explicable. In that study, the animals were run for 21 sessions of 2 hr and 6 min each using a nine-stimulus sequence from the start. When the data from the entire training period were averaged, no effect was measured.

The present data indicate that the number of stimuli initially presented influences the development and maintenance of differential responding. In the case of Group I when only three stimuli were presented, differential responding developed rapidly, was

maintained consistently for the duration of the three-stimulus condition, and continued to be evident with increasing numbers of stimuli. This suggests an "attention mechanism" whereby it is possible to shape the animals to listen to a large number of stimuli. This multiplicity of stimuli would not maintain differential responding if presented from the start, as with Group II or in Hegge *et al.* Such an analysis suggests that the disappearance of differential responding in Group II occurred because the animals may in fact have been learning *not* to listen. Additional support for this view is provided by the Group II discrimination training data. These animals did learn to discriminate between 60 and 100 db once differential reinforcement was provided, but they did so much more slowly than a comparable group given no prior non-differential exposure to the stimuli.

The major finding of the study, however, is that a stimulus intensity-response rate relationship can be obtained with a simple operant. We can obtain graded responding that is a direct function of the magnitude of intensive stimuli in the absence of differential reinforcement. Since the definition of "stimulus control" rests on the relationship between response strength and some parameter of the stimulus, it is clear that control by stimulus intensity can be produced without differential reinforcement. This study provides an instance in which differential reinforcement is not a necessary condition for the acquisition of stimulus control.

Our findings also may help to clarify an apparently similar result found by Kiefer (1965). In his study, rats emitted higher rates of responding in the presence of a buzzer than in its absence, even though the lever-pressing response was consistently reinforced on a fixed-interval 2-min schedule in both stimulus conditions.

Such a demonstration of differential responding as a function of stimulus intensity without differential reinforcement raises the question of the definition of the term "stimulus control". If stimulus control refers to any and all instances of differential responding produced by any and all manipulations of stimuli, the term becomes virtually meaningless, becoming synonymous with psychology itself, or at least with most problems included within an S-R analysis. Whether the term should be restricted to differential responding produced by reinforcement operations; to differential responding produced by stimuli demonstrably serving a discriminative function; or limited by some other restricting rule is not clear from the history of usage. What more restrictive definition would prove most useful is also not immediately obvious. The frequency and variety of usage of the term indicates the need to make some decisions either to delimit the class of stimulus-response relationships defining stimulus control, or to accept the proposition that virtually all S-R psychology is in practice encompassed by this concept.

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Received 14 August 1970.