

## ANALYSIS OF RESPONSE RATES DURING STIMULUS GENERALIZATION<sup>1</sup>

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In the presence of one click frequency, the presses of two hungry rats on one of two levers were reinforced with food on variable-interval schedules; in the presence of a different click frequency, presses on the other lever were reinforced. In stimulus generalization tests, a variety of click frequencies were presented and reinforcement withheld. The test stimuli were found to exert control over which of the two levers the rats pressed, but not over the rate of pressing the selected lever. The results were interpreted as further evidence that intermediate rates in generalization gradients may be the result of the alternation of several distinct behavior patterns.

When an organism's responses are reinforced on a variable-interval schedule, a stable response rate may emerge. This stable rate can be shown to be partly under the control of the stimulus ( $S^D$ ) in the presence of which the response was previously reinforced. For instance, in brief tests without reinforcement, stimuli distantly removed from the original training stimulus typically produce lower response rates (*cf* Guttman and Kalish, 1956; Pierrel and Sherman, 1962). How are these lower rates to be explained? One possibility is that such diminished response rates in the presence of "distant" stimuli constitute a basic datum, and cannot be reduced to other variables. But another possibility is that these reduced response rates are the result of averaging distinctive different response patterns. Occasional periods of responding at the usual ( $S^D$ ) rate, controlled by the prior schedule history in the  $S^D$ , are averaged with irregularly alternating periods of little or no responding. The result is a composite "low" response rate. Such an analysis is compatible with data of Blough (1963), Sewell and Kendal (1965), and Crites, Harris, Rosenquist, and Thomas (1967), who consistently found that stimuli distant from the  $S^D$  produced inter-response time (IRT) distributions that differed from the  $S^D$  IRT distribution only in an increased frequency of very long IRTs.

IRT analyses suggest that a mixing of different response topographies may be responsible for generalization "gradients", but IRTs alone provide little information concerning the composition of any behaviors being mixed. In the usual generalization study, only one response class is systematically measured. Any other competing behaviors that might be contributing to a composite response rate must be inferred from the absence of the measured response or, more generally, from multi-modal distributions of IRTs (Migler, 1964). The present experiment examined more closely the composite responding explanation of stimulus generalization gradients by making alternative behaviors identifiable. A multiple-response discrimination paradigm in which two incompatible responses were brought under the differential control of two different stimulus situations was used to provide the behavioral baseline.

### METHOD

#### *Subjects*

Two experimentally naive adult male albino rats served in daily sessions. Rat 1 (16-hr food deprived) ran eight consecutive hours during the day, Rat 2 (15-hr food deprived) ran nine consecutive hours overnight. The free-feeding weights of the subjects before the experiment began were 490 and 494 g respectively. At the conclusion of the experiment five months later, they weighed 494 and 473 g respectively.

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### Apparatus

The experimental chamber was constructed of Plexiglas 9-in. high and 12-in. deep and wide, and was housed in a sound-resistant box. A Gerbrands pigeon key (0.75-in. diameter) was mounted on the rear wall 1.5 in. from the floor (at nose height) and could be illuminated from behind. Two microswitch levers, 2-in. wide, were mounted on the front wall 6-in. apart center-to-center. A pellet hopper was located between the levers near the floor, and a speaker was mounted behind the front wall. Reinforcement consisted of the simultaneous delivery of two 45-mg Noyes rat pellets from two independent dispensers operating simultaneously. Water was available at all times in the experimental and home chambers. Sound stimuli were delivered from a Foringer click generator. Scheduling and recording were accomplished with conventional relay circuitry.

### Procedure

**Training.** Each animal was trained to emit the following response sequence. Pushing the illuminated nose key on the rear wall turned off the illumination on the key and turned on a clicking noise, either 2.5 clicks per sec, or 25 clicks per sec. This defined the beginning of a trial. During the 2.5 clicks/sec stimulus ( $S_L$ ), pressing on the left lever ( $R_L$ ) was reinforced with food pellets, on the schedules given in Table 1, while pressing on the right lever ( $R_R$ ) went unreinforced. During the 25 clicks/sec stimulus ( $S_R$ ), pressing on the right lever ( $R_R$ ) was reinforced on the schedules also given in Table 1, while pressing on the left lever went unreinforced. When reinforcement was delivered, the clicker stimulus was terminated, ending the trial, and the key light reilluminated. The next key push turned off the key light starting the next trial, and so on. The sequence of clicker stimuli on succeeding trials was random except that a particular stimulus could not be repeated on more than three consecutive trials.

The reinforcement schedule on the lever designated "correct" was continuous (CRF) during the first training session, followed by VI 9-sec until comparable response rates were obtained on each lever when it was correct. The schedules on each lever were then gradually altered (see Table 1) to produce a high

Table 1

Table of training schedules and number of sessions exposure to each.

Schedule of Reinforcement		Sessions
$S_R:R_R$	$S_L:R_L$	
CRF	CRF	1
VI 9-sec	VI 9-sec	17
VI 60-sec	VI 30-sec	8
VI 120-sec	VI 30-sec	40
VI 226-sec	VI 30-sec	44

response rate on  $R_L$  when it was correct, but a low response rate on  $R_R$  when it was correct. The purpose of establishing these two differential patterns was to provide two widely separate but stable anchor points along the response-rate dimension for comparison with any intermediate rates that might develop to test stimuli intermediate in value between the two training stimuli.

During training trials, the first correct lever response after a key push started the VI tape associated with that lever. This contingency was designed to encourage short latencies between the key push starting the trial and the beginning of lever pressing. A response on the incorrect lever stopped the tape, which could be restarted only by the next correct response. To discourage superstitious switching between levers even more, the first correct response after an incorrect response could never be reinforced. Throughout training, a trial ended when a reinforced lever response occurred.

**Testing.** Stimulus generalization testing consisted of inserting probe trials during the last 32 experimental sessions, during which time the schedules were VI 226-sec in  $S_R$  for  $R_R$ , and VI 30-sec in  $S_L$  for  $R_L$ . Probes were carried out in the following manner. On every eleventh trial, the nose key was illuminated as usual. When the key was pushed, a click frequency was presented as usual. When the first response occurred on either lever, a 1-min timer started. When it timed out, the clicker stimulus was terminated and the key reilluminated. On these probe trials the probability of reinforcement was zero. After the probe trial, 10 regular training trials with the usual reinforcement schedules occurred, followed by a probe trial, and so on, for the duration of the session.

**Stimuli.** Normally, when a key press produced a clicker rate of 2.5 clicks/sec,  $R_L$  was

reinforced on VI 30-sec. Normally, when a key press produced a click rate of 25 clicks/sec, responding on  $R_R$  was reinforced on VI 226-sec. During stimulus generalization probe tests, however, a key press produced a click rate having one of the following eight values: 0.4, 1.6, 2.5, 9.5, 15.6, 20, 25, and 55 clicks/sec. The two regular training stimuli, 2.5 and 25 clicks/sec, were included in the test series. Nevertheless, regardless of the click frequency value, reinforcement never occurred during probe trials.

**Data collection.** All data reported below are from the performance on probe trials only. The value of the probe stimulus was constant during each session. Eight sessions were therefore required to complete a test across the entire stimulus continuum. Four such complete tests or replications across the eight stimuli were carried out. Two kinds of response rates were obtained. (1) Total  $R_R + R_L$  press output during the 1 min of the probe stimulus following the first lever response. (2) Differential "running" response rates on each lever. During the probe trials, the number of responses made to each lever was divided respectively by the amount of time spent "on" each lever. The amount of time spent "on" each lever was obtained from accumulating time counters associated with each lever. When the first lever press occurred in a probe trial, a steady pulse stream was directed into the associated counter. If the animal switched to the other lever before the trial was over, the pulse stream was then directed into the counter associated with the other lever, and so forth. In addition to running response rates based on these times, IRT distributions were also obtained for each lever. Only the second of two consecutive responses on the same lever provided tallies for these distributions; that is, the first response in the probe trial and the first response after a switch did not enter the IRT distributions, although they did enter the response-rate counters.

## RESULTS

Figure 1 shows the average total lever-response rates during probe trials for each of the four replications of generalization testing. The dependent variable in Fig. 1 represents the average rate of lever pressing, disregarding lever position, during various test click fre-

quencies. The curves of Fig. 1 may be described by reference to their three distinct segments. Looking from left to right, click frequencies below and including 10 clicks per sec are associated approximately with the same relatively high rate that is found at the VI 30-sec training point. Between 10 clicks/sec and the VI 226-sec point, however, a sharply declining rate gradient is found. Finally, the low rate at 50 clicks/sec suggests a low-rate asymptote for frequencies above the VI 226-sec training point.

Figure 2 presents data for the percentage of time spent "on" the right lever,  $R_R$ , during the various probe stimuli. The figure shows that when the probe stimulus was similar to  $S_R$ , the animal spent most of its time responding on  $R_R$ . As the probe stimulus value approached  $S_L$ , less time was spent on  $R_R$  and more on  $R_L$ . At those stimulus values (20 and 15.6 clicks/sec) where a sizeable percentage of

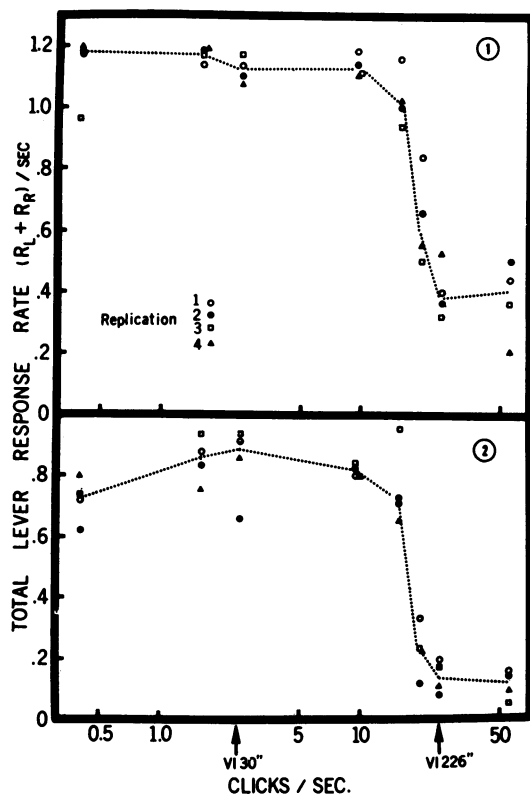


Fig. 1. Average total lever-response rate in probe trials, for each rat, for each of the four replications. Each point represents the data for all the probe trials in one session and is calculated from cumulative  $R_L + R_R$  frequencies over cumulative probe times for that session. Dotted lines connect medians.

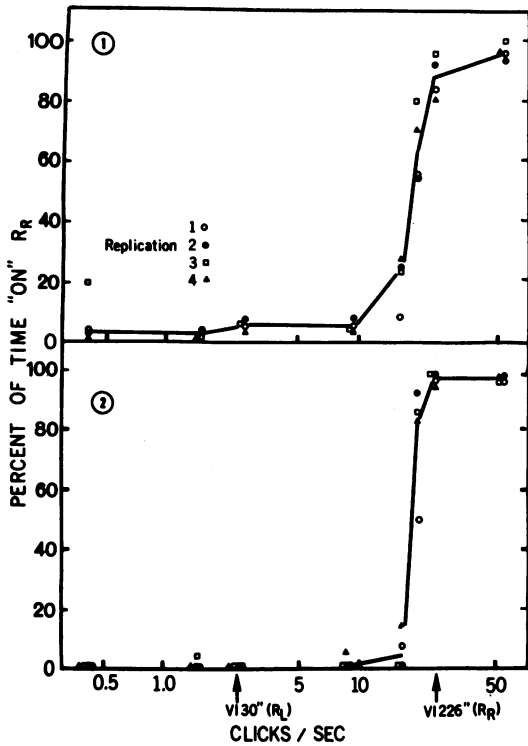


Fig. 2. Percentage of total time in probe trials spent on the right lever, for each rat, for each of the four replications. Each point represents the data for all the probe trials in one session, and is calculated from total time on  $R_R$  divided by the total time "on" both levers. Lines connect medians.

time was spent on each lever, cumulative response records (not presented) show that the animal selected one lever on one probe trial and the other on a later probe trial. Switching between levers occurred rarely during either training or probe test trials.

Figure 3 presents running response rates "on" each lever during the probe stimuli. When 20 or fewer responses occurred in a session, these response-rate calculations were considered to be of questionable value and were therefore excluded from the figure. The exclusions account for the absence of a left-hand limb for the  $R_R$  curves, and the absence of a right-hand limb for the  $R_L$  curves. Figure 3 shows that stable running response rates were obtained on each lever. These stable rates were widely separated, however, and there were no discernible systematic changes associated with probe stimulus value or replication series.

A more intimate view of the individual running response rate data is provided by the

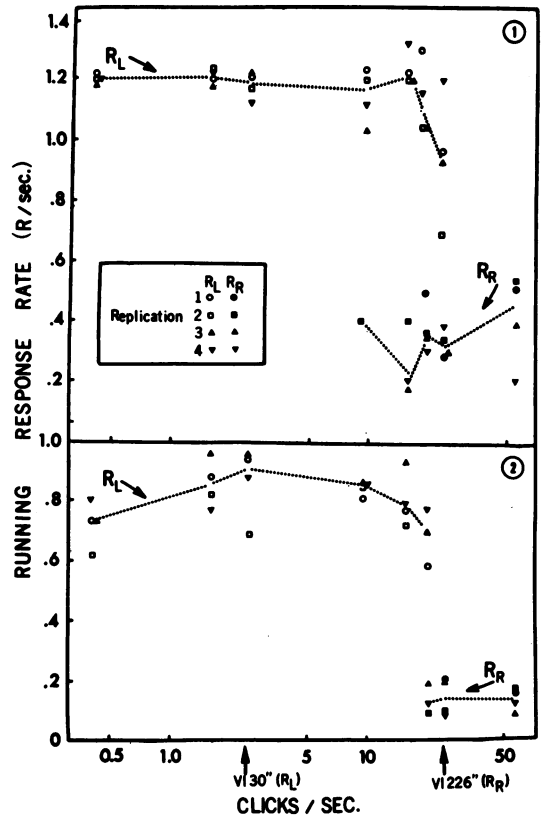


Fig. 3. Response rates "on" each lever for all four replications, for each rat. Each point represents the average response rate for all the trials in one session. The right-hand limbs of the  $R_L$  curves, and the left-hand limbs of the  $R_R$  curves are short due to insufficient samples of behavior at those points (see text). Dotted lines connect medians.

distribution of  $R_L - R_L$  and  $R_R - R_R$  IRTs taken from the first of the four test replications and shown in Fig. 4. Each circle data point in Fig. 3 is represented by an IRT distribution in Fig. 4. Examination of the Fig. 4 IRT distributions confirms the independence of  $R_L$  and  $R_R$  running rates from the values of the test stimuli. The IRT data for the remaining three replications (not shown) were similar in nature to those of Fig. 4, departing only in details.

## DISCUSSION

Although the percentage of time spent on each lever (Fig. 2) was under the control of the probe stimulus value, the running response rates (Fig. 3) and their corresponding IRT distributions (Fig. 4) were not. The test

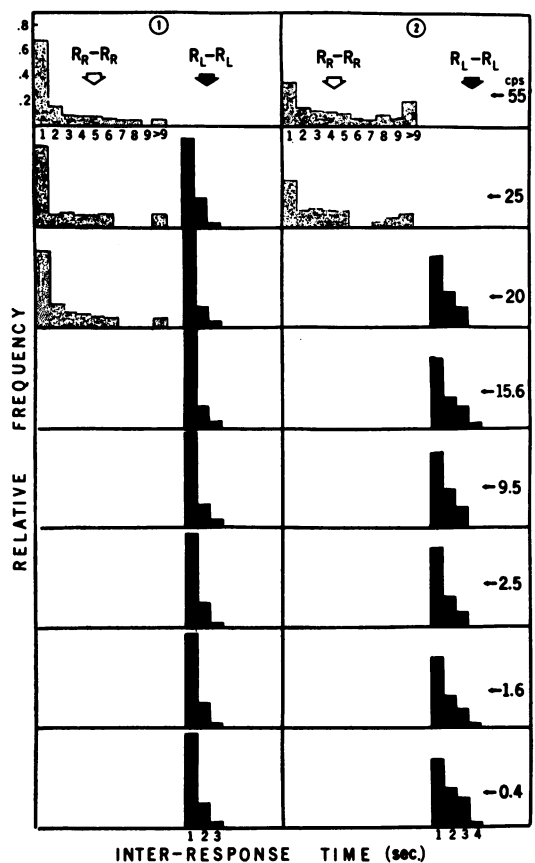


Fig. 4. Distribution of interresponse times for each rat, for each lever, for all replications, for each solid and open circle points in Fig. 3. Class intervals are 1-sec wide. The associated test frequencies in clicks per second (cps) are shown as numerals at the extreme right of each panel.

stimuli apparently exerted control over which response was initiated—that is, the probability of responding on the left or the right lever—but once the response had been selected, the running response rate itself remained under the strict control of the prior schedule history, *i.e.*, reinforcement of a low rate of response on  $R_R$  and a high rate on  $R_L$ . The combination of these two results, (1) invariant running response rates and (2) differential test-stimulus control of time spent on each lever, is sufficient to account for the overall response-rate gradients of Fig. 1.

The failure to find intermediate response patterns at intermediate test stimuli confirms findings of Cross and Lane (1962) in a two-response discrimination paradigm with human subjects. After establishing selective control by two intensities of tone over two vocal

operants differing in pitch, test tones were introduced at intermediate intensities. Although the probability of responding with one or the other of the two pitch responses was found to be related to the distance of the test tone from the respective training tone, subjects showed no tendency to respond to any intermediate pitch responses at these intermediate test tones.

The rate gradients of Fig. 1 of the present experiment show little evidence of the shifting of the peak away from the less favorable of the two training stimuli, as has been previously reported. Although Guttman (1959) found this kind of a peak shift along the wavelength dimension with pigeon subjects using a single response procedure and VI 60-sec reinforcement at 550  $m\mu$  and VI 300-sec reinforcement at 570  $m\mu$ , he gave his subject many fewer hours of exposure than were given the present subjects. By the time of the first stimulus generalization test, the present rats had received over 400-hr exposure to different VI schedules, probably long enough to have dissipated emotional effects (of which a peak shift seems to be one symptom) generated by the contrast in reinforcement density between VI 30-sec and VI 226-sec (Terrace, 1966).

Migler (1964) suggested that the lowered response rates that constitute generalization "gradients" might be the result of averaging periods of responding at the rate controlled by the training stimulus with periods of little or no responding. Where the test stimulus was distant from the positive training stimulus, most of the time would be spent not responding, with occasional brief periods of responding at the training stimulus rate. The average of these distinct behaviors would be a low overall response rate. Stimuli close to the positive training stimulus would produce fewer periods of little or no responding, and many periods of responding at the rate controlled by the training stimulus, averaging out to an intermediate overall response rate, and so forth. The way in which generalization gradients may be produced by averaging different proportions of two separate and stable temporal performances in the presence of a stimulus has been demonstrated (Migler, 1964). Animals were trained to pause several seconds between pressing two levers ( $R_R$  and  $R_L$ ) sequentially for reinforcement in one positive training stimulus. In a second positive train-

ing stimulus, no pause was required between  $R_R$  and  $R_L$ . Generalization testing with stimuli intermediate between the two training stimuli produced intermediate average response times between  $R_R$  and  $R_L$ . But these average values were found to be the result of averaging short and long  $R_R - R_L$  IRTs, rather than the result of intermediate  $R_R - R_L$  IRTs. As in the present experiment, the test stimulus controlled the probability of responding in one of two fashions. The temporal characteristics of the behavior remained under the control of the prior reinforcement history; that is, only short or long IRTs had been reinforced regularly in the past and therefore only short or long IRTs occurred during stimulus generalization testing.

The present data provide additional evidence that during stimulus generalization tests, a test stimulus may control principally the probability with which one of several previously established behaviors will be chosen. The full generality of this conclusion to other stimulus generalization settings remains to be assessed. In the present study, the two training stimuli,  $S_{R^+}$  and  $S_{L^+}$ , and all the test stimuli, lay along a common dimension and two response classes were differentially reinforced. For that condition, at any rate, the sloping rate profile between these stimuli, usually called a gradient, may convincingly be derived as a composite of two well-learned response patterns. Furthermore, for those cases where training has been between a single  $S^D$  and an  $S^A$ , we may consider the absence of responding conditioned in  $S^A$  to be one of the previously learned patterns, and so derive the portion of the rate gradient between  $S^D$  and  $S^A$  as a special case of the present results. But other studies suggest that a distant test stimulus affects not only the probability of which learned behaviors will be selected, but also whether any will be selected. For instance, Honig and Shaw (1962) trained pigeons to peck at the rightmost of two keys when both keys were identically illuminated by 530-m $\mu$  light. When both keys were illuminated with 590-m $\mu$  light, pecks on the left key were reinforced. In generalization tests at five intermediate wavelengths, Honig and Shaw found the total response rate on both keys to be less than at either of the training stimuli. Running rates, as defined here, were not examined in that study. But if these pigeons were re-

sponding at the conditioned rates when they did respond, as the present results would suggest, then it follows that the birds were not always responding to either key. One possibility is suggested by Cross and Lane's (1962) finding from discrete-trial responding that, in the presence of intermediate test stimuli, subjects in generalization tests exhibit long latencies before beginning to respond. In the present experiment, since measurement of lever-pressing rates did not begin until the first lever response following a key push, such latencies did not enter into the rate calculations, and as their possible significance was not suspected at the time, they were not recorded.

The present technique might usefully be extended to cases where  $S_{R^+}$  and  $S_{L^+}$  lie on orthogonal dimensions (for example, a tone and a light) with test stimuli drawn exclusively from one or the other dimension (for example, tones of various frequencies, or lights of various intensities). Under such conditions, the measured strengths of  $R_R$  and  $R_L$  should provide an empirical method for determining whether a third class of behavior (which could include an inhibitory mechanism as suggested by Jenkins, 1965) must be introduced to account for the generalization gradients known to occur in these situations (Jenkins and Harrison, 1962; Honig, Boneau, Burstein, and Pennypacker, 1963).

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