

*AUDITORY GENERALIZATION GRADIENTS FOR
RESPONSE LATENCY IN THE MONKEY¹*DAVID B. MOODY, WILLIAM C. STEBBINS, AND CAROL IGLAUER²

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Two monkeys were trained to press and hold a response key in the presence of a light and to release it at the onset of a pure tone. Initially, all responses with latencies shorter than 1 sec were reinforced without regard to the frequency of the pure tone, and the intensity of the pure tone that resulted in equal latencies at each frequency was determined. The second stage of the experiment consisted of discrimination training, during which releases to one pure-tone frequency (positive stimulus) were reinforced and releases to a second frequency (negative stimulus) were extinguished. Median latencies to the negative stimulus slowly increased as did the variability of the latency distribution for the negative stimulus. There was no evidence of a concurrent decrease in latencies to the positive stimulus indicative of behavioral contrast. The third part of the experiment consisted of determining maintained generalization gradients by increasing the number of nonreinforcement stimuli. The gradients that eventually resulted showed approximately equal latencies to all frequencies of the negative stimulus and shorter latencies to the positive stimulus frequency.

The use of sophisticated behavioral techniques in recent years has added a great deal to knowledge of the stimulus control of operant behavior. Much of this knowledge, however, is based on observations of a single dependent variable: rate of responding. Although rate is widely accepted, in many instances it does not adequately specify behavior. For example, Blough (1963) demonstrated that the "rate differences" seen in stimulus generalization studies are produced mainly by an upward shift of longer interresponse times (IRTs), while the short IRTs are relatively unaffected. He interpreted these data as indicating that stimulus control is exerted only over the responses following long IRTs and that the occurrence of responses following short IRTs is controlled by the preceding response. The average rate measure concealed this feature of behavior; IRT distributions did not. Blough (1965) suggested that rate is a "hodgepodge" consisting of such components as (1) response probability, given a previous

response, and (2) latency of response following stimulus onset. He added: "A unitary component would have a much better chance of behaving in a neat manipulable manner than the conglomerate 'rate' usually used" (1965, p. 32). Latency of response following stimulus onset is related by definition to the occurrence, and hopefully to the value, of some stimulus. In the present study, response latency is used both as a measure of the formation of a discrimination on an auditory frequency continuum and as a measure of maintained post-discrimination generalization.

Latency has been used to a limited extent to study the phenomena of stimulus control (*e.g.*, Terrace, 1963*a, b*; Farmer, Schoenfeld, and Harris, 1966; Winograd, Cohen, and Cole, 1965; Jenkins, 1961). Two problems are frequently encountered when the latency measure is used. The first is that suitable contingencies are not included to control where the animal is in the chamber at the moment of stimulus onset. The inclusion of key approach time in the latency increases variability and may hide the latency differences related to the value of the stimulus. The second problem is that no latency can be measured if the animal fails to respond. Since well-trained subjects seldom respond to the negative stimulus (S-), few latencies enter into the S- sample. Latency is frequently discarded as a useful dependent

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variable (*e.g.*, Skinner, 1950) simply because the situation in which it is measured fails to eliminate these problems and therefore fails to yield orderly data. Stebbins and Lanson (1961), however, suggested a procedure for measuring latencies that presents neither of these problems. Their procedure requires that the animal hold down a bar to produce a stimulus and then release it for the reinforcer and proceed to the next trial. Stebbins and Reynolds (1964) showed that in a standard positive-negative stimulus training paradigm, latencies become much longer to the negative stimulus than to the positive (S+).

Another problem of using latency as a dependent variable is that it varies inversely with the intensity of the stimulus: more intense (louder or brighter) stimuli produce shorter latencies than do less intense stimuli (Stebbins, 1966; Moody, 1969, 1970). Fortunately, the functional relationships between latency and intensity can be accurately specified. The intensity problem can be circumvented by using those intensities of various stimuli that under non-differential reinforcement conditions can be shown to produce equal latencies. Stebbins (1966) and Moody (1969, 1970) have suggested that this "equal latency" procedure is useful in defining equal loudness or equal brightness for non-verbal subjects.

In studies of stimulus control that have used response rate as the dependent variable, two phenomena have frequently been encountered: behavioral contrast and the peak shift. Behavioral contrast refers to an increase in strength of responding to S+ that accompanies a decrease in strength of responding to S- (Reynolds, 1961). The peak shift (Hanson, 1959) refers to a shift in the maximum strength of responding measured in a post-discrimination generalization gradient away from S+. The direction of the shift is to the side of S+ away from the original S-. In previous studies, these phenomena have usually covaried; the necessary condition for their occurrence would appear to be response suppression to S- (Terrace, 1968).

The generality of these findings is somewhat limited by the fact that although behavioral contrast has occasionally been demonstrated with latency (Terrace, 1963*a, b*; Jenkins, 1961), the covariance of contrast and the peak shift have only been studied when rate is the de-

pendent variable. One of the purposes of the present experiment was to extend the use of the latency measure to a situation in which both contrast and the peak shift could occur. If we assume latency is inversely related to measures of response strength, such as rate, the above definitions of contrast and the peak shift can be applied to latency data by substituting "decrease in latency" for "increase in strength" and so on.

METHOD

Subjects

Two adolescent male macaques (M-9, a *Macaca fascicularis*, and M-22, a *Macaca nemestrina*) were maintained in individual living cages except during experimental sessions, when they were placed in modified primate restraining chairs (Moody, Stebbins, and Miller, 1970). They had free access to water, but were 22-hr food deprived before each daily session. The monkeys' daily food ration totalled about 80 g and consisted of 190 mg whole diet pellets (Ciba) which served as reinforcers, plus Purina monkey chow. They also received a fresh fruit supplement.

M-9 had electrodes implanted in auditory cortex in connection with a previous frequency discrimination experiment and had been trained to produce short latencies using a limited hold procedure (Miller, Glickstein, and Stebbins, 1966). M-22 also had cortical implants, but had no prior frequency discrimination history.

Apparatus

The monkeys were put into restraining chairs and then placed in a double-walled soundproof room (Industrial Acoustics). Their heads were restrained and calibrated human earphones (Permoflux-PDR-600), on universal swivel joints, were carefully placed over the external ear (Moody *et al.*, 1970). A modified version of the feeder described by Thompson, Schuster, Dockens, and Lee (1964), was placed near the animal's mouth and a small light was mounted on the feeder. A telegraph key was mounted at the far end of an 8 in. (20 cm) long by 3 in. (7.5 cm) diameter Plexiglas tube. The tube, designed to minimize variations in response topography, was fastened to the restraint chair at waist level.

The auditory stimuli were generated by a Hewlett Packard (200CD) oscillator or a Wave-tek (155) programmable signal generator. The intensity was controlled by a programmable attenuator. The auditory stimuli were gated by a tone switch that had a rise and decay time of 5 msec. Contingencies were arranged by solid-state logic (BRS) and a digital computer (PDP-8). Latencies were recorded by the computer on punched paper tape for later analysis.

Procedure

The animals had been trained previously to press and hold the telegraph key in the presence of the light and to release it at the onset of the tone. Key release terminated the tone and the light. Latency was measured (in msec) from tone onset to key release. All releases that terminated latencies shorter than 1 sec were reinforced. Following an intertrial interval of 5 sec without a response, the light was again presented. The interval from key press in the light until tone onset was randomly varied between 1 to 4 sec. Key release before tone onset terminated the light and started a new intertrial interval. The present study consisted of three parts: equal loudness determination, discrimination training, and maintained generalization testing.

Equal loudness determination. Each pure tone to be used in the subsequent parts of the experiment (0.5, 1, 2, 4, 8, 12, and 16 kHz) was presented at several different intensities. Only one frequency was presented in a given session, and the intensity was varied in 10-db steps over a 60-db range with the order determined by a modified Gellerman series. All key releases that met the 1-sec limited hold criterion were reinforced regardless of the frequency of the tone. The frequency-intensity combinations that resulted in median latencies of about 290 msec for M-22 and 500 msec for M-9 were used in subsequent discrimination training and generalization testing. Because the data from M-9 at 16 kHz were unstable, that frequency was omitted during generalization testing. The intensities were checked for equal latency after the initial determination by conducting several sessions in which the frequency of the pure tone was varied in a modified Gellerman series. During these sessions, the intensity values just determined were used, but minor adjustments were made where necessary to pro-

duce approximately equal latencies at all frequencies. The range of sound pressures employed was between 52 and 79 db re 0.0002 dyne/cm².

Discrimination training. After equal latency (equal loudness) was determined, discrimination training was started. Only two frequencies were presented. To the frequency designated as S+, all releases that satisfied the 1-sec criterion were reinforced. Releases to S- were not reinforced, but the animal was required to release the key to progress to the next trial. For M-9, S+ was 4 kHz and S- was 1 kHz; for M-22, S+ was 1 kHz and S- was 8 kHz. The stimuli were again presented in a modified Gellerman series. During a session, each stimulus was presented approximately 175 times. Training was continued until S- latency had stabilized within a 50-msec band for three consecutive sessions.

Maintained generalization testing. When a stable discrimination had developed, responses to S+ continued to be reinforced, but the 175 trials previously devoted to S- were equally divided among the original S- and the other frequencies for which equal loudness had been determined. Each daily median was based on approximately 175 trials for S+, 30 trials for each S- frequency for M-22, and 35 trials for each S- frequency for M-9. This part of the experiment was continued until a stable discrimination, evidenced by approximately equal latencies to all values of S-, had developed.

RESULTS AND DISCUSSION

The acquisition of the discrimination is shown in Fig. 1 for both animals. The session numbered 0 represents the final baseline session in which there was no differential reinforcement. For M-22 (Fig. 1a), latencies to S- began to increase during Session 6 and continued to increase until Session 14, when an error resulted in reinforcement of all releases to both stimuli for that one session. Discriminative performance recovered quickly and the terminal behavior showed stable S+-S- latency differences of at least 200 msec. An important feature of these data is the relatively constant latencies to S+ of about 350 msec; there was no decrease in S+ latency indicative of a contrast effect.

The behavior of M-9 (Fig. 1b) showed no evidence of a discrimination until about Ses-

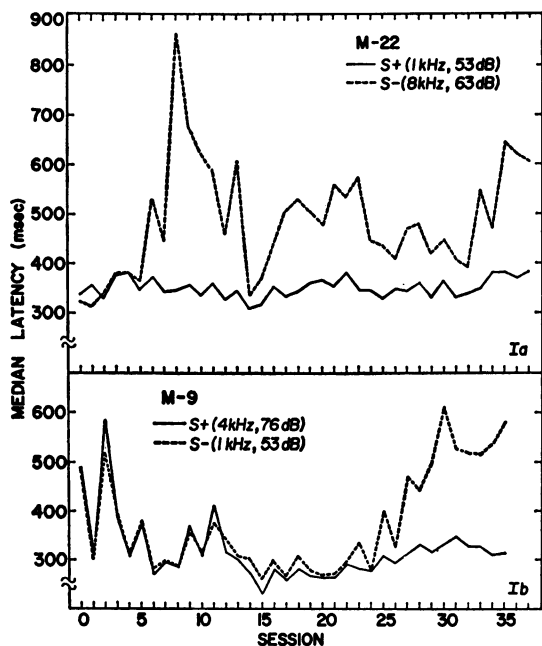


Fig. 1. Median latencies to S+ and S- as a function of session number during discrimination training. Session 0 represents the last day of non-differential reinforcement.

sion 25, when discriminative performance began to develop quite rapidly. At the end of discrimination training, there was approximately a 200-msec difference between S+ and S- latencies, with S+ latencies stabilizing at about 325 msec. During the initial discrimination training session, the median S+ and S- latencies dropped sharply for this animal. This drop may have been a result of earlier training, during which short latencies were differentially reinforced. The two situations resemble each other in the considerable decrease in reinforcement density that occurs in both. When S+ and S- latencies began to separate, there was no evidence that S+ latencies showed any contrast effect; in fact, the S+ latencies slightly increased, indicating an induction effect.

Several possibilities exist for the failure to observe contrast in the present experiment. One is that the animals were already responding at or near minimum latencies. To test this possibility, in a subsequent experiment with M-22, short latency responses to the S+ stimulus were differentially reinforced. Under these conditions, M-22 reliably produced median latencies in the range of 275 msec—about 50 msec below its final S+ latencies. However,

since there was nothing in the present situation analogous to the long interresponse times typical of variable-interval performance (Blough, 1963), but which are reduced when contrast occurs, the possibility of a "floor effect" cannot be ruled out.

Other possible explanations for the failure to observe contrast include (1) lack of response suppression to S- (Terrace, 1963a, 1963b, 1968); (2) high density of reinforcement in S+ (Reynolds, 1963); (3) lengthy prior histories of the subjects (Terrace, 1966); and (4) the slow rate of acquisition (Pierrel, Sherman, Blue, and Hegge, 1970). Further experiments with suitable controls will be required to determine which variables are responsible for the lack of contrast in the present data.

Figures 2 and 3 show frequency distributions of latencies for the final sessions of discrimination training for M-22 and M-9 respectively. Aside from the obvious differences in median latencies to S+ and S-, the outstanding difference shown by these figures is the substantially greater amount of variability in S- responding, thus confirming results of Stebbins and Reynolds (1964). It is also apparent in the data of M-22 (Fig. 2) that there is an almost complete dichotomy between S+ latencies and S- latencies. Specifically, latencies longer than 475 msec almost always occur to S-, and latencies shorter than that value al-

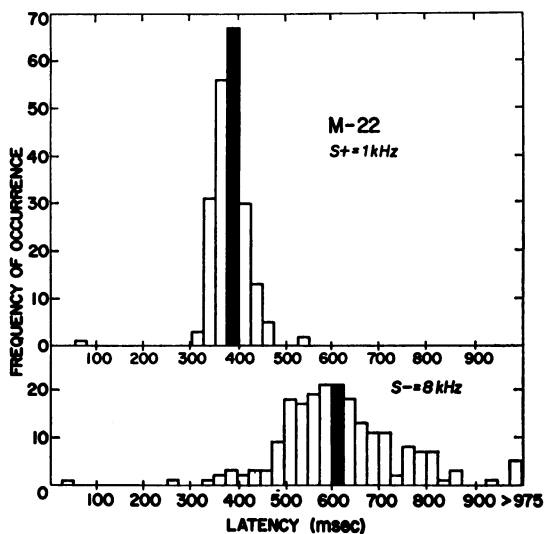


Fig. 2. Frequency distributions of latencies to S+ and S- for M-22 for the last day of discrimination training. The class interval containing the median has been filled in.

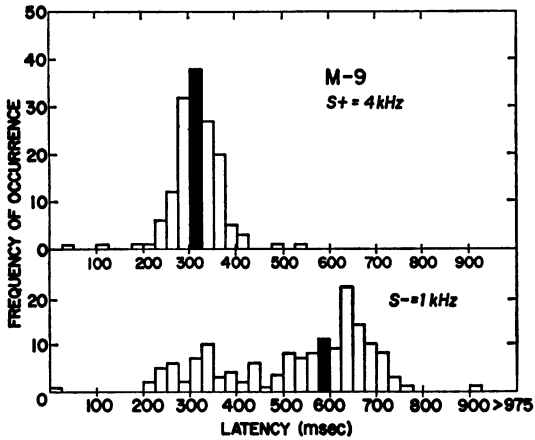


Fig. 3. Frequency distributions of latencies to S+ and S- for M-9 for the last day of discrimination training. The class interval containing the median has been filled in.

most always occur to S+. This dichotomy is not quite as clear in the data of M-9 because there are many S- latencies in the general range of the S+ distribution. Very few S+ latencies, however, fall into the range where the S- distribution peaks.

To illustrate the course of development of the gradients during maintained generalization testing, groups of five successive gradients were averaged together (Fig. 4 and 5). To make these gradients more directly comparable to gradients of response rate (*i.e.*, with a maximum at S+), the reciprocal of latency in seconds has been plotted.

For M-22 (Fig. 4), Days 1 to 5, latencies to 0.5 kHz were roughly comparable to those for 1 kHz (S+), while latencies to 2 kHz, one oc-

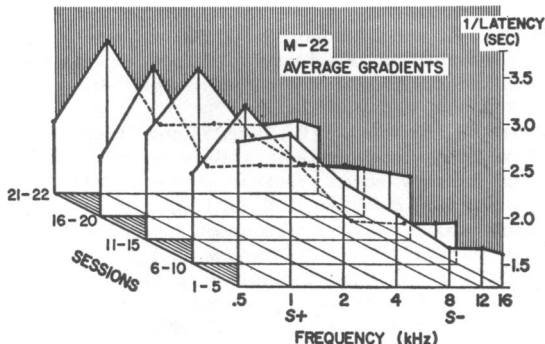


Fig. 4. Average maintained generalization gradients for M-22. The reciprocal of latency in seconds has been plotted as a function of frequency. Each gradient except the last one represents the average of five daily gradients.

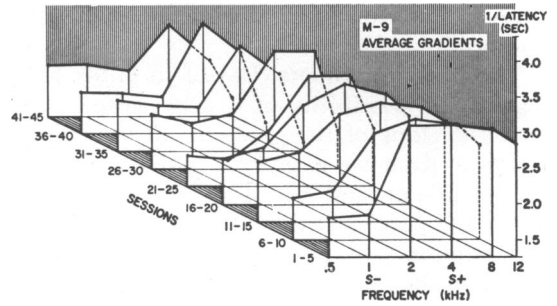


Fig. 5. Average maintained generalization gradients for M-9. The reciprocal of latency in seconds has been plotted as a function of frequency. Each gradient represents the average of five daily gradients.

tave away from S+ toward S-, were somewhat longer (hence 1/latency became less). Latencies to 4 kHz were somewhat shorter than to 8 kHz (S-), but those to 12 and 16 kHz were approximately equal to those to 8 kHz. By Days 6 to 10, latencies to 4 kHz had become comparable to latencies to 8, 12, and 16 kHz, and latencies to 0.5 kHz had also become longer. This gradual sharpening of the gradient increased as testing continued until approximately Session 16, when median latencies to all values of S- were very similar. From Session 16 on, this pattern of equal latencies to all S- values continued virtually unchanged, thus replicating the prior equal loudness determination. Latencies to S+ remained at approximately 350 msec throughout maintained generalization testing. This value is very close to S+ latencies obtained during the period of discrimination training.

Similar results were obtained from M-9 (Fig. 5). Initially, 2, 4, 8, and 12 kHz were responded to with approximately equal latencies, as were 0.5 and 1 kHz. These gradients sharpened similarly to those for M-22: increases in latency first appeared at 2 kHz, the frequency between S+ and S-. Responses to 12 kHz, over 1.5 octaves above S+, also showed similar increases in latency. After 30 sessions of maintained generalization testing, latencies to 0.5, 1, 2, and 12 kHz had all become approximately equal. However, latencies to 8 kHz, also an S-, remained the same as latencies to S+. After 45 sessions, although latencies to 8 kHz had increased, they were still below the other S- frequencies. Latencies to 12 kHz were longer than those of any of the other S- frequencies. Median S+ latencies showed more intersession variability (between 310 and 460 msec) for this

animal than for M-22 during generalization testing.

The initial gradients (Days 1 to 5) for M-22 suggest the possibility of a peak shift-like effect: the slope of the gradient on the side of S+ away from S- is much less than the slope on the side toward S+. This effect resembles the "area shift" mentioned by Terrace (1964). An asymmetry is also present in the gradients of M-9 in the direction predicted by theoretical interpretations of the peak shift (Spence, 1937), but it does not become obvious until Sessions 21 to 25. Previous studies of maintained generalization gradients using a rate measure (Pierrel and Sherman; 1960, 1962) have shown peak shift effects early in testing, which disappeared as the new discrimination developed. Therefore, it is rather surprising to see the pronounced asymmetry as late as Sessions 26 to 30 of maintained testing.

Several explanations are possible for the failure to obtain an unequivocal peak shift effect. First, Terrace (1968) may be correct in saying that contrast and the peak shift occur together as a result of the same conditions. A second possibility is that the spacing of the original S+ and S- was so large that no peak shift would occur even if conventional training and testing procedures were employed. In the original demonstration of the peak shift (Hanson, 1959), the amount of shift was roughly related to the wavelength difference between S+ and S-, but very little is known about the auditory frequency continuum in this regard. The only reported peak shift on this continuum (Jenkins and Harrison, 1962) occurred when S+ was 1000 Hz and S- was 950 Hz. The shift was to 1050 Hz. Data on the monkey's frequency difference threshold show $\Delta F/F$ values of the order of 0.01 (Stebbins, Pearson, and Moody, 1970), also suggesting that the lack of a strong peak shift may be the result of choice of S+ and S- stimulus spacing.

The present procedure, and the latency variable, appear to have certain advantages over more conventional rate procedures for the study of stimulus control. One is that the time scale for the formation of the discrimination and the development of the gradients is expanded, allowing a more detailed study of these transition states. Another advantage is that it allows pre-discrimination latencies to be equated by varying the intensities of the various stimuli. This equation seems to result

in equal latencies following discrimination training.

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