COMPARISON OF YES-NO AND LATENCY MEASURES OF AUDITORY INTENSITY DISCRIMINATION

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Rats discriminated auditory intensity differences of sinusoids at 3.0 kilohertz in a go/no-go signal detection procedure. Responses to the signal (hits) were reinforced with electrical brain stimulation, and misses produced a brief timeout. On intermixed noise trials, withholding of responses (correct rejections) was reinforced, and false alarms produced the timeout. In two test conditions, the signal was either the louder (100 decibels) or softer (90, 93, 96, or 99 decibels) of the pair of intensities presented within a set of trials. Each animal was first trained with signal value louder or softer, and reversed for the second condition so that the former noise value served as signal. Hits showed shorter latencies than false alarms, regardless of the relative intensity of signal and noise, and the magnitude of differentiation was proportional to signal-noise separation. Both hits and false alarms showed longer latencies as the discrimination became more difficult. Isosensitivity contours derived from the latencies showed close similarity across conditions; in comparison, the yes-no measure of detectability, d', showed greater variability. The similarity of latency differentiation across louder and softer signal conditions supports a detection model in which the observer's judgment is controlled by the distance of sensory effect from criterion on each trial, as opposed to the loudness of the tones per se.
Key words: animal psychophysics, go/no-go procedure, latency differentiation, stimulus intensity dynamism, signal detection, criterion, audition, rats

Evaluating an organism's capacity to discriminate stimuli has been based traditionally on the relative frequency of a specified reporting response to different stimuli. In a typical case, responses to one stimulus (S+) are reinforced while responses to others (S−) are extinguished or punished. Since correct and incorrect responses may be members of the same experimenter-defined response class (e.g., verbal "yes" reports or key presses), it has been inferred that responses to S−, errors, represent failures in discrimination. This interpretation is based on the view that all members of the response class are "quantitatively mutually replaceable" (Skinner, 1969, p. 351).

Skinner noted, however, that imprecision in response measurement may lead to erroneous conclusions about the functional equivalence of responses. The analysis may be clarified by examining indices of discrimination other than the relative frequency of reporting responses.

In psychophysical procedures, for example, the report is always accompanied by a latency (or reaction time), which goes unmeasured in many experiments. In an early study, Henmon (1906) showed that the correct and incorrect responses of observers releasing a telegraph key could be distinguished by mean latency. Recent experiments have shown that correct responses are made with generally shorter latencies than are errors in a variety of species such as goldfish (Yager & Duncan, 1971), rat (Hack, 1966; Terman, 1970; Terman & Terman, 1973), monkey (Clopton, 1972; Moody, Stebbins & Inglauer, 1971; Stebbins & Reynolds, 1964) and human (Cross & Lane, 1962; Emmerich, Gray, Watson & Tanis, 1972; Sekular, 1965). Response differentiation on the basis of latency suggests that the subject may demonstrate some degree of discrimination even when emitting errors.

In such experiments the S+, which controls shorter latencies, has typically been of greater physical intensity than S−. Hull (1949) argued that organisms may respond differentially to stimuli solely on the basis of stimulus intensity. His concept of stimulus intensity dynamism predicts shorter latencies to stimuli of

greater intensity even without a differential reinforcement contingency. The stimuli are viewed as having an unconditioned "dynamogenic" effect proportional to intensity. Dynamism could thus account for the shorter latencies found for correct responses in many psychophysical tests.

Few experiments allow assessment of the relative contributions of stimulus intensity dynamism and differential reinforcement contingencies to latency. In one, Terman and Terman (1973) found latencies to be shorter for correct responses made to the brighter stimulus in a luminance discrimination by rats. When differential reinforcement was discontinued and all responses were reinforced regardless of stimulus luminance, the latency difference disappeared. Yager and Duncan (1971) and Farmer, Schoenfeld, and Harris (1966) analyzed generalization gradients of latency along a luminance continuum. The gradients of Yager and Duncan showed slightly faster responding to stimuli on the more intense limb. The gradients of Farmer et al. showed little difference between the more and less intense limbs. While it is clear that dynamism effects can be obtained (e.g., Moody, 1969), their relation to stimulus control and the differential reinforcement contingency remains unclear.

The present experiment examines differentiation of responses by latency, as well as by the frequency of "yes" and "no" reports, in an auditory psychophysical test. Rats were trained to discriminate between sine tones differing only in intensity. In one condition, responses to the more intense of two tones were reinforced; the procedure was reversed in the second condition, so that responses to the less intense tone were reinforced. Asymmetry of the results across conditions, it was reasoned, could reflect a dynamism effect interacting with the reinforcement contingencies. Latencies were compared for correct and incorrect reports as the intensity difference of the tones was varied. An index of auditory detectability based on scaled latency classes was contrasted to one based on the binary distribution of go and no-go responses.

METHOD

Subjects

Three male pigmented rats (Lewis B/N strain, Microbiological Associates) received sur-gical implants of bipolar stainless steel electrodes (Plastic Products MS 303) used to deliver reinforcing brain stimulation in the posterior hypothalamic area. They were fed 20 g of Purina Lab Chow daily, and allowed free access to water in their home cages.

Apparatus

The experimental box was constructed of clear Plexiglas sides and aluminum end walls, measuring 32.0 cm by 24.0 cm by 49.0 cm. A Gerbrands pigeon key, with an incandescent transillumination lamp, was mounted 5.1 cm above the grid floor on the midline of each end wall, serving to sense "set-up" and "reporting" responses. The box was kept inside a sound attenuating chamber furnished with an overhead pulley-swivel mercury commutator (Berkley & Kling, 1967) that connected to the brain-stimulation electrode lead. A 60-Hz constant-current sine wave stimulator provided .5-sec stimulation trains for reinforcement adjusted to an intensity that maintained rapid responding. (Use of this reinforcer in discrimination studies has been discussed by Terman & Kling, 1968.)

A University 4401 loudspeaker was suspended from the ceiling of the chamber 57.0 cm above the grid floor, directly over the set-up key. Auditory stimuli were produced by a Hewlett-Packard 220C sine wave oscillator set at 3.0 kHz. The signal was passed by an electronic switch (5.0 msec rise and decay times) and one of two attenuators en route to the loudspeaker. Tone intensity was calibrated by placing the remote microphone of a sound level meter directly beneath the loudspeaker, .5 cm in front of the set-up key. This location approximated the position of the rat's head at tone onset.

The test procedure was controlled by standard relay and solid state logic located in a room separate from the chamber. Data were registered on an event recorder and counters, and latency distributions were assembled on-line by a PDP-12 computer.

The animals were trained to perform a discrimination between two tones which differed only in intensity. Following signal detection terminology, these tones were called "signal" and "noise." Unlike the usual situation, however, the signal could be either the louder or the softer of the tone pair. For clarity in describing the situation of a signal softer than

noise, we refer here to the "signal" alone, rather than the conventional designation of "signal plus noise." Responses to the signal were defined as "hits" and were reinforced; failures to respond were "misses" and produced a timeout. Responses to noise were "false alarms" and produced a timeout; absences of the response were "correct rejections" and were reinforced.

One rat was trained with the signal as the louder of the two tones (100 vs. 75 dB re 20 $\mu N/m^2$). In this case, responses to the louder tone were hits, and responses to the softer tone were false alarms. Subsequently, the procedure was reversed so that the signal was the softer tone. In this case, responses to the softer tone were hits, and responses to the louder tone were false alarms. Two other rats received the opposite sequence, i.e., they were first trained with the soft signal and then reversed to the loud signal.

The animals were taught a self-paced chain in which a set-up response on one key produced the auditory stimulus, initiating each trial. Responses (hits or false alarms) were recorded when the rat pressed the yes report key at the other end of the box. If no response occurred within 4.0 sec of the set-up, a failure to respond (either a miss or correct rejection) was recorded. Following either reinforcement or a timeout, the rat was free to initiate a new trial at any time by pressing the set-up key. Each response key was transilluminated when its specific function (i.e., set-up or report) was in effect.

A fading procedure was used to train final discrimination performance. Initially, the signal was presented on every trial. This was necessary to teach the rat to run through the chain of pressing the set-up key, making reinforcement available on the report key, and then pressing the set-up key again for the next trial. After the rat had run through the chain a few hundred times without long pauses, initial discrimination conditions were set with (a) signal probability of .9, (b) tones at 100 dB and 20 dB, (c) choice time at 10 sec, (d) tone duration at 10 sec, and (e) hits producing reinforcement, but false alarms, misses, and correct rejections terminating the trial without timeout or reinforcement.

The experimenter trained the rats to perform at the testing baseline by progressively changing each of the five variables (a through
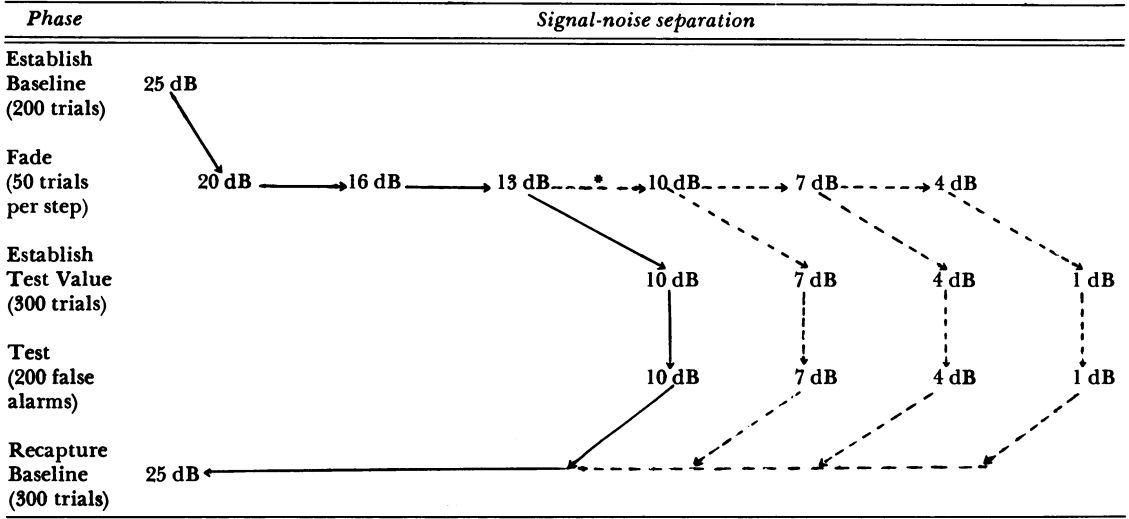
e above) within daily sessions. At baseline, signal probability was .6, tone intensities 100 and 75 dB, choice time 4 sec, tone duration .5 sec, and symmetrical reinforcement and timeout dependencies in effect. (Timeout consisted of a 4.0-sec period during which all response consequences were suspended.) The major problem encountered during fading was that, if a strong no-response bias developed, the rat would first cease responding on the report key and eventually cease making the set-up response. Therefore, the correct rejection dependency, which reinforced correct "no" responses, was not introduced until the rat showed a high level of discrimination performance. Further, the .6 signal probability encouraged a moderate yes-response bias (see Results).

Once the rats achieved nearly perfect discrimination at 25-dB signal-noise separation, daily test sessions were begun. The course of test sessions is summarized in Table 1. All sessions began with 200 trials at 25-dB signal-noise separation, which proved sufficient to establish a nearly errorless baseline. Then, the softer intensity was increased in discrete fading steps of 50 trials each to the value to be tested. At that value, 300 additional trials were run before the test began, insuring stability of the response pattern. Test data were collected until 200 false alarms accumulated. The number of trials required to generate 200 false alarms depended on the animal's discrimination accuracy and bias and varied between 500 and 8000 trials across sessions. After the test, signal-noise separation was returned to 25 dB and another 300 trials conducted. By recapturing the high-accuracy baseline at the end of each session, we successfully prevented deterioration of performance over successive days.

The 4 test values, which included signal-noise separations of 10, 7, 4, and 1 dB, were run in mixed order for approximately 20 sessions each, by which time visual inspection of raw latency distributions showed negligible day-to-day variability. The data presented were pooled over three final sessions at each signal-noise separation, under both loud and soft signal conditions. With a minimum sample size of 1500 trials per condition, statistical variability of d', the detection index, was minimized (Green & Swets, 1966).

In the first testing condition, Rat 10E was

Table 1

Procedural Sequence for Test Sessions

Phase	Signal-noise separation
Establish Baseline (200 trials)	25 dB
Fade (50 trials per step)	20 dB ⟶ 16 dB ⟶ 13 dB ---*-- → 10 dB ----- → 7 dB ----- → 4 dB
Establish Test Value (300 trials)	10 dB 7 dB 4 dB 1 dB
Test (200 false alarms)	10 dB 7 dB 4 dB 1 dB
Recapture Baseline (300 trials)	25 dB ←

*Dashed arrows denote extensions of fade to test values below 10 dB.

trained to report the louder signal (100 dB) and to withhold responses to the softer noise; Rats 3G and 12H were trained to report the softer signal (99, 96, 93, or 90 dB). In the second condition, the procedure was reversed, so that each rat was trained to report the alternate stimulus. All three rats stopped responding early in reversal training and required brain stimulation current increases to reinstate behavior; at that point, Rat 3G failed to respond at the maximum available current amplitude (1.10 mA$_{p-p}$) and was therefore not given the second condition.

RESULTS

Yes-No Differentiation

The data were analyzed with respect to the frequency with which reporting responses were made to the two stimuli. Following the analogy to human psychophysical procedure, the key-press response was considered a "yes" report (signal judged present) and withholding of the response a "no" report (signal judged absent). In yes-no detection paradigms (Green & Swets, 1966), the psychometric function that quantifies stimulus discriminability across varying stimulus differences can be expressed as in isobias function, which correlates hit and false alarm probabilities (cf. Terman, 1970). Figure 1 presents isobias functions for the three animals. Points lying closest to the major

diagonal (which represents chance performance with respect to the stimuli) were obtained at 1 dB signal-noise separation. Points falling farther from the major diagonal on a given isobias function follow increasing signal-noise separation. The range of d' (the detectability index that assumes equal variance in
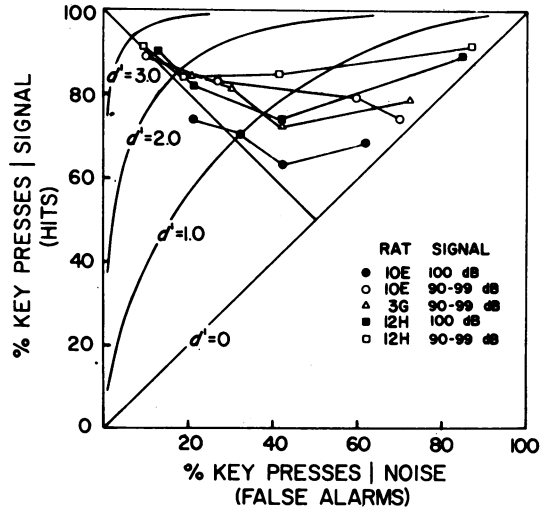

Fig. 1. Isobias functions for individual animals at signal-noise separations of 10, 7, 4, and 1 dB. One stimulus (signal or noise) was always 100 dB, with the second stimulus attenuated. Signal probability = 0.6. Contours of equal d' illustrate varying levels of detectability within the unit square. The distance of points from the major diagonal is proportional to signal-noise separation, within each isobias function.

normal distributions of sensory effect for signal and noise) spans approximately .3 to 2.5 over the range of 1 to 10 dB signal-noise separation. These levels of detectability correspond closely to data obtained earlier on the rat (Terman & Terman, 1972).

One isobias function, for Rat 10E, appears displaced from the main cluster; in the test condition requiring key-press reports to the loud signal, d' reached only 1.43 at 10 dB signal-noise separation. Further, the entire function fell closer to the minor diagonal, indicating a reduced bias toward yes (key-press) reports.

The isobias functions in Figure 1 show little deviation from the minor diagonal at the 10-dB signal-noise separation but gradually increasing deviation to the right (tendency toward yes reports) as signal-noise separation was reduced. At 1 dB separation, the animals all showed proportions of yes re- sponses exceeding .6 (the proportion of signal trials). This indicates a tendency to maximize the proportion of reinforcements as control by the auditory stimuli decreased.

Latency Differentiation

The go/no-go procedure allows measurement of a latency only when a report of the signal is made (i.e., on go, or yes, trials). On no-go trials, when the report was withheld, exactly 4.0 sec elapsed after stimulus presentation before a correct rejection or miss was recorded; thus, those response classes could not be differentiated on the basis of latency. The latency analysis focuses on the subset of yes trials (which includes all hits and false alarms), when an explicit reporting response occurred before 4.0 sec.

The differentiation of hit and false alarm latency distributions is illustrated in Figure 2. By cumulating latencies for each signal-noise
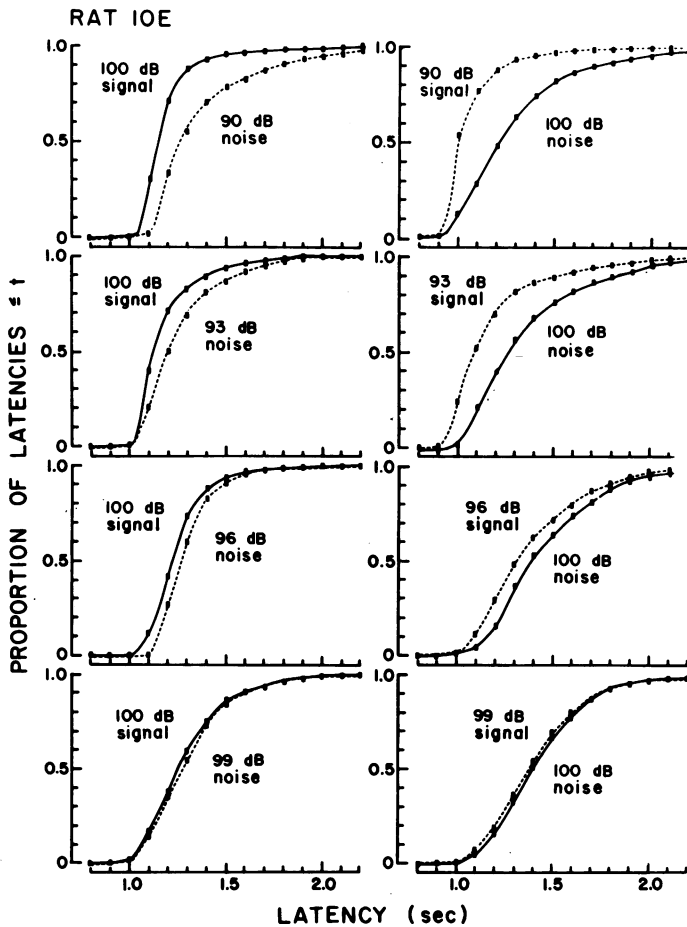

Fig. 2. Cumulative latency distributions for hits and false alarms, across loud and soft signal conditions. Smooth curves fitted by eye.

condition, skewed ogival functions result, typical of poisson distributions for reaction time (McGill, 1963). Data are presented for Rat 10E, whose contrasting isobias functions based on yes-no data (Figure 1) might lead to a prediction of contrasting latency functions as well. Yet the forms of the distributions, and trends in latency differentiation as a function of signal-noise separation, show marked similarity across loud and soft signal conditions and serve well to represent the corresponding data for the other two animals.

Latencies, which were measured from the moment of the set-up response to the moment of the hit or false alarm report, were rarely less than 1.0 sec in duration. The larger the signal-noise separation, the more rapid the initial rise in the cumulative distributions and more gradual the approach to upper asymptote. False alarm distributions show latencies consistently exceeding those of hits. The magnitude of displacement of the distributions for a given tone intensity pair is proportional to signal-noise separation. At 10 dB difference, the median false alarm latency was approximately 150 to 200 msec longer than that of a hit; at 1-dB difference, the two classes of latency were drawn nearly together. Latency values for the stimulus held constant within each condition (100-dB signal or noise) were a function of signal-noise separation rather than of absolute intensity: average latency increased as the discrimination became more difficult. This trend toward increased latency was true also for the stimulus whose intensity was varied within each condition (90- to 99-dB noise or signal) even though its intensity was increased as the discrimination became more difficult. Thus, a dynamism effect, in which louder tones are associated with shorter latencies, was not found.

Latency trends for Rats 3G and 12H resembled those of Rat 10E (summaries presented below). However, while all three animals showed generally longer latencies with increasing discrimination difficulty, Rat 12H showed a decrease in mean latency of approximately 100 msec between 4- and 1-dB signal-noise separations. Correspondingly, there was a swing toward a relatively extreme yes bias at 1-dB separation (see Figure 1) under both loud and soft signal conditions.

The latency differentiation effect was further examined by considering latency classes
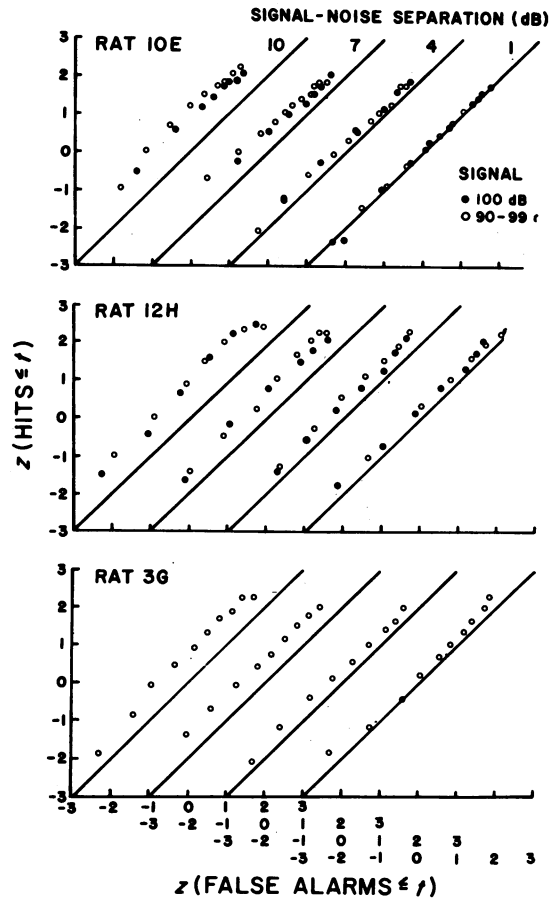

Fig. 3. Isosensitivity contours (normal probability coordinates) derived from hit and false alarm latency distributions, as a function of signal-noise separation. Filled circles, louder signal; open circles, softer signal. The major diagonal has been laterally displaced for each data set in order to clarify the visual display. From left to right within each contour successive points represent the proportion of hit and false alarm latencies falling into interval bins $\leq t$, with t incremented in 100 msec steps throughout the latency range.

as a rating measure of signal detectability (cf. Hack, 1966). Such an analysis is based on the subset of trials on which the animal emits a yes report; trials without key presses (correct rejections and misses), which do contribute to yes-no discrimination measures, are excluded. This procedure should be distinguished from a similar analysis that confounds scaled latencies with yes-no data (Yager and Duncan, 1971). The hit and false alarm latency distributions were partitioned into 100 msec bins. In Figure 3, the percentage of responses in the shortest bin was plotted against the percentage of false alarms in that bin, producing the
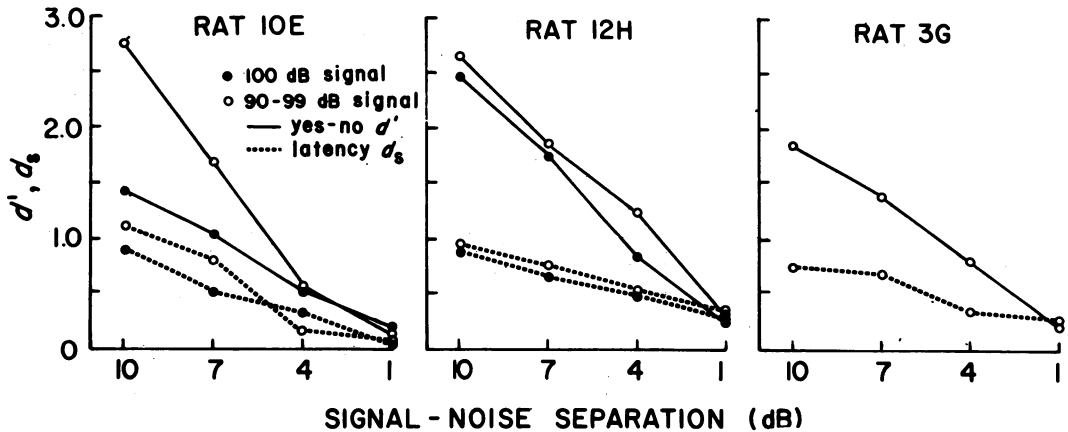
Fig. 4. Discriminability indexes for yes-no proportions (d') and the corresponding latency differentiation of hits and false alarms (d_s), as a function of signal-noise separation.

left-most point in each set of data. The adjacent data point was plotted for the percentage of hits and false alarms in the first two bins. By successively increasing the bin size used to define a hit and false alarm, and plotting successive points on normal-normal coordinates, we generated isosensitivity curves based on latency alone. The farther a row of points lies upward and to the left of the major diagonal, the greater the latency differentiation between hits and false alarms. The larger differentiation between hit and false alarm latencies, proportional to signal-noise separation, signifies a greater degree of stimulus control exhibited exclusive of concurrent yes-no data.

The scaled data points fall on straight lines which are approximately parallel to the major diagonal. These latency contours appear similar regardless of whether hits were made to the louder or softer signal. Taking all data across animals and conditions into account, the mean slope of a line fit through the points by the least-squares method was .97, with a standard deviation of .08. An estimator of d', d_s, can be conveniently derived from the contours by calculating the point at which the best-fitting straight line through each set of points crosses the minor diagonal (Green & Swets, 1966). This parameter provides an unbiased index of latency differentiation, and has been found to change little with variations in the slope of isosensitivity contours (Markowitz & Swets, 1967). The d_s values increased from approximately .3 at 1-dB signal-noise separation to 1.0 at 10-dB separation (see Figure 4).

In order to appreciate the magnitude of this effect, a d_s of 1.0 can be roughly translated into an accuracy of 69% correct, attributable to the latency of yes reports without reference to the degree of yes-no differentiation.

Comparison of Yes-No and Latency Data

Figure 4 compares psychometric functions based on the yes-no d' and latency d_s measures across all experimental conditions. Both detectability measures grow monotonically as functions of signal-noise separation, for loud and soft signal conditions. Both functions are approximately linear and approach zero with decreasing signal-noise separation. This is to be expected for unbiased estimators of sensitivity (Wright, 1974). Over the 1- to 10-dB range of signal-noise separation, however, yes-no d' grew at a faster rate than did latency d_s. In general, both latency and yes-no measures were slightly higher when the signal was the softer tone, regardless of the order of testing across animals. The small magnitude of this effect suggests that the particular tone intensity specified as signal had a negligible influence on detectability.

If stimulus intensity dynamism contributed to the latency differentiation between hits and false alarms, latencies to the louder tone of a pair would be selectively shortened. Thus, in the loud signal condition, the hit and false alarm latency distributions would show greater differentiation, and d_s would be augmented. Such an effect would result in steeper slopes for the latency d_s functions under the loud

signal condition in Figure 4. However, the similarity in slopes suggests that dynamism does not contribute to the latency differentiation.

DISCUSSION

Differential behavior under stimulus control is usually assessed by the relative frequency with which a particular response is made to different stimuli. In the present experiment, this was indexed by d', which compares the frequency of yes responses to signal and to noise. However, further evidence for stimulus control was found by differentiating the yes responses on the basis of latency. Latencies may therefore provide supplementary evidence of discrimination not implicit in the yes-no frequency scores. Even when false alarm errors were made, the rats exhibited some degree of discrimination in that they showed longer latency on those occasions. Thus, by Skinner's (1969) criterion, correct and incorrect responses are not "quantitatively mutually replaceable."

However, the binary and latency measures linearly approached zero as the signal-noise separation decreased. Therefore the present data suggest that latencies do not provide evidence of stimulus control in the absence of concurrent yes-no differentiation (see also Terman & Terman, 1973). In this sense, the two measures of discrimination are redundant. Note, however, the relative consistency of latency d_s functions across animals and conditions (Figure 4), in comparison to the yes-no d' functions. In particular, Rat 10E showed an atypical isobias function (Figure 1) and yet produced latency data consistent with the other animals, which suggests that latency-based measures may provide a more reliable index of discrimination performance than yes-no reports.

Two-choice procedures contrast with the present go/no-go design in that both yes and no reports are explicitly emitted. The no report is not merely defined as the absence of a yes, and the two classes of response are specified symmetrically. In the two-choice case, a latency is measureable on every trial, and thus a measure of differentiation of correct and incorrect no reports, in addition to yes reports, can be derived in terms of latency. Available data suggest that both report classes show differentially shorter latency when correct (Ter-

man, 1970; Clopton, 1972). Thus, such a result is not limited to go/no-go procedures. However, it should be noted that position preferences as well as report accuracy determine latencies in the two-choice situation, complicating the analysis of latencies as a rating measure of stimulus detectability; in the go/no-go situation, where all responses are to one position, the analysis is clarified.

Since, in the present experiment, the latency trends were similar across the loud and soft signal conditions, it is doubtful that unconditioned energizing effects of stimulus intensity contributed to the latency differentiation. Rather, the differentiation should be attributed to the operant discrimination. Still, it is possible that variations of our procedure might reveal a dynamism effect. Pierrel, Sherman, Hegge, and Blue (1970) suggested that dynamism may habituate with training. Each of our rats ran more than 500,000 trials over the course of training and testing. Furthermore, we used relatively high tone intensities. It has been shown that latencies decrease to an irreducible minimum as an exponential function of stimulus intensity (Pieron, 1952; Moody, 1969; Stebbins, 1966).

That shorter latencies were associated with correct responses and not with greater stimulus intensity per se suggests that models of choice behavior must be neutral with respect to the effects of stimulus intensity. For example, our data are not accounted for by McGill's (1963) neural count model, in which the reporting response is emitted when a criterion number of nerve impulses is produced by a stimulus. By that model, intense stimuli cause faster neural firing and therefore quicker responding. By contrast, our data show shorter latency responses to signals softer than noise.

A model based on the relationship between response criterion and sensory effect distributions is consistent with our results. Gescheider, Wright, Weber, Kirchner, and Milligan (1969) proposed that sensory effects falling farther from the observer's criterion for the yes-no decision lead to shorter latencies. In differentiating signal from noise, the observer does not directly compare the two tones (or their sensory effects), but rather the position of the yes-no criterion with respect to the value of sensory effect produced on each trial. In the usual case, with signal intensities greater than noise, an observer with a moderate yes bias would

place his criterion toward the left of the sensory effect distributions (Figure 5a). Under a reversed situation, as with our softer signal, the noise presentations would generate generally stronger sensory effects than would signals, so the observer would place his criterion toward the right of the distributions (Figure 5b), maintaining the relative relationship of sensory effects to criterion. In both loud and soft signal conditions, the distance of the sensory effects of signals from criterion tends to exceed that of noise. Thus, the signals are generally easier to discriminate from criterion, leading to differentially shorter hit latencies. The symmetry of our latency data across loud and soft signal conditions supports such a view.

The Gescheider et al. model implies that latencies are influenced by response bias as well as by signal-noise separation. For example, Terman and Terman (1973) differentially reinforced correct responses to one of two luminances projected on a report key. The results are similar to the present findings in that shorter latencies were made for correct responses. However, when the animals were switched to nondifferential reinforcement, with all responses reinforced, the latency differen-

tiation to the two luminances disappeared. The Gescheider et al. model accommodates this result by taking into account the large bias shift toward the yes response. Figure 5a shows an example where criterion placement would produce a yes bias of the kind found under differential reinforcement by Terman and Terman (1973). The latency differentiation would be moderate since there is a relatively greater distance from criterion to the mean of the signal distribution falling on the yes side of the decision axis compared to that of the noise distribution. When responses are nondifferentially reinforced and a response is made on every trial, a situation like that shown in Figure 5c exists. Now the criterion is located far to the left of both signal and noise distributions. Note that although there is still a difference between the means of the signal and noise distributions, distances from criterion to the distributions, in proportional terms, are nearly equal. Thus, nondifferential reinforcement produces an extreme yes bias, which in turn results in smaller latency differentiation. A corollary prediction is that since the criterion moves far from the signal and noise distributions, nondifferential reinforcement should result in overall faster latencies. This prediction was also verified by Terman and Terman (1973), for the animals' latencies did markedly decrease under nondifferential reinforcement.

In addition to the three rats studied under differential reinforcement in the present study, we also trained two other rats to respond nondifferentially to two 3.0-kHz tone intensities presented in random sequence across trials, at 100 dB and various attenuated values. As a result, these animals developed an exclusive yes-response bias. Latency-based isosensitivity contours were constructed from their data. With a 10-dB separation between the tones, d_s was only .10 and .11, compared to values ranging between approximately .75 to 1.20 for the differential animals at the same tone intensities (Figure 4). Furthermore, the nondifferential animals showed latencies much shorter than those of the differential animals, providing a further confirmation of the Gescheider et al. model.

The tendency for faster responding with increasing yes bias is also found for cases in which the shift in bias is less extreme. For example, Clopton (1972) shifted signal probability over a range from .3 to .7, and obtained
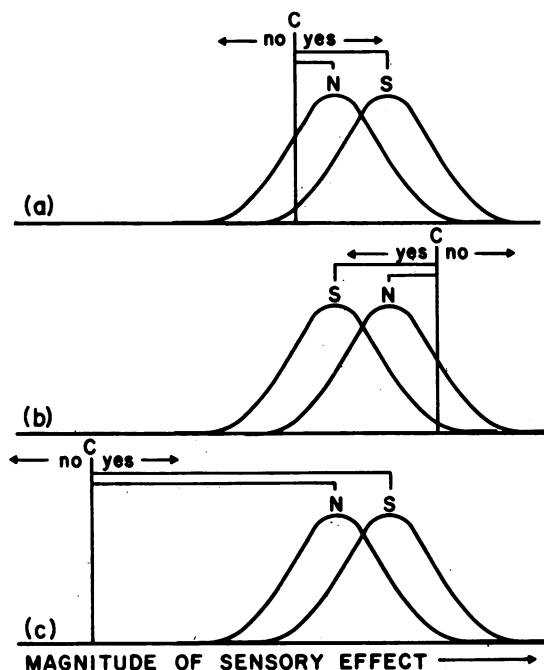

Fig. 5. Probability density distributions of sensory effect for signal and noise, with varying criteria for the yes report (panels a, b, and c). C, criterion; S, signal; N, noise.

a moderate change in response bias. With higher signal probabilities and a greater proportion of false alarms, overall latencies decreased, as the model predicts. Indeed, the classical human reaction time literature is consistent in finding that nondifferential reinforcement (i.e., "simple" reaction time) produces smaller latency differentiation and faster responding than does differential reinforcement (i.e., "choice" reaction time).

In summary, the observer's response bias may affect overall latency values as well as the magnitude of latency differentiation. Since evidence of sensory detectability can be derived from these latencies, it is possible that a range of variables affecting response bias (e.g., signal probability, reinforcement asymmetry, or asymmetry in yes and no response requirements) can interact with stimulus intensity in determining behavioral measures of discrimination (cf. Nevin, 1970).

REFERENCES

Berkley, M., & Kling, J. W. A small animal coupler with vertical movement compensation. *Physiology and Behavior*, 1967, 2, 315-316.

Clopton, B. Detection of increments in noise intensity by monkeys. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 473-481.

Cross, D. V., & Lane, H. On the discriminative control of concurrent responses: The relation among response frequency, latency and topography in auditory generalization. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 487-497.

Emmerich, D., Gray, J., Watson, C., & Tanis, D. Response latency, confidence and ROC's in auditory signal detection. *Perception and Psychophysics*, 1972, 11, 65-72.

Farmer, J., Schoenfeld, W. N., & Harris, A. Generalization gradients from "reaction time" or latencies of the white rat to visual brightness. *Psychonomic Science*, 1966, 4, 23-24.

Gescheider, G., Wright, J., Weber, J., Kirchner, B., & Milligan, E. Reaction time as a function of occurrence of vibrotactile signals. *Perception and Psychophysics*, 1969, 5, 18-20.

Green, D. M., & Swets, J. A. *Signal detection and psychophysics*. New York: Wiley, 1966.

Hack, M. Receiver-operating characteristics in the rat. *Journal of Auditory Research*, 1966, 6, 229-234.

Henmon, V. A. C. The time of perception as a measure of difference in sensations. *Archives of Philosophy, Psychology and Scientific Method*, 1906, no. 8.

Hull, C. L. Stimulus intensity dynamism (V) and stimulus generalization. *Psychological Review*, 1949, 56, 67-76.

Markowitz, J., & Swets, J. A. Factors affecting the slope of empirical ROC curves: Comparison of binary and rating responses. *Perception and Psychophysics*, 1967, 2, 91-97.

McGill, W. J. Stochastic latency mechanisms. In R. F. Luce, R. R. Bush, & E. Galanter (Eds.), *Handbook of mathematical psychology* (Vol. 1). New York: Wiley, 1963.

Moody, D. Equal brightness function for suprathreshold stimuli in the pigmented rat: A behavioral determination. *Vision Research*, 1969, 9, 1381-1389.

Moody, D., Stebbins, W. C., & Inglauer, C. Auditory generalization gradients for response latency in monkeys. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 105-111.

Nevin, J. A. On differential stimulation and differential reinforcement. In W. C. Stebbins (Ed.), *Animal psychophysics*. New York: Appleton-Century-Crofts, 1970.

Pieron, H. *The sensations*. New Haven: Yale University Press, 1952.

Pierrel, R., Sherman, J. G., Hegge, F., & Blue, S. Auditory discrimination: A three variable analysis of intensity effects. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 17-35.

Sekular, R. W. Signal detection, choice response times, and visual backward masking. *Canadian Journal of Psychology*, 1965, 19, 118-132.

Skinner, B. F. *Contingencies of reinforcement: A theoretical analysis*. New York: Appleton-Century-Crofts, 1969.

Stebbins, W. C. Auditory reaction times and the derivation of equal loudness contours for the monkey. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 135-142.

Stebbins, W. C., & Reynolds, R. Note on changes in response latency following discrimination training in the monkey. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 229-231.

Terman, M. Discrimination of auditory intensities by rats. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 145-160.

Terman, M., & Kling, J. W. Discrimination of brightness differences by rats with food or brain stimulation reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 29-37.

Terman, M., & Terman, J. S. Concurrent variation of response bias and sensitivity in an operant-psychophysical test. *Perception and Psychophysics*, 1972, 11, 428-432.

Terman, M., & Terman, J. S. Latency differentiation of hits and false alarms in an operant-psychophysical test. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 438-446.

Wright, A. A. Psychometric and psychophysical theory within the framework of response bias. *Psychological Review*, 1974, 81, 322-347.

Yager, D., & Duncan, I. Generalization in goldfish using latency as a graded response. *Perception and Psychophysics*, 1971, 19, 353-355.