

*AUDITORY DISCRIMINATION: A THREE-VARIABLE ANALYSIS OF INTENSITY EFFECTS*<sup>1</sup>ROSEMARY PIERREL, J. GILMOUR SHERMAN,<sup>2</sup>  
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The acquisition of auditory intensity discriminations in rats trained on multiple variable-interval extinction schedules was studied as a function of some of the variables that contribute to the speed of development of differential responding and the final level attained. The effects of three variables were isolated and studied in detail: (1) the decibel difference between the discriminative stimuli (intensity difference); (2) the intensity relationship between the stimuli (relative intensity); and (3) the position of the stimuli on the intensity continuum (absolute intensity). Each of the three variables generated orderly relationships and interacted with one another to produce complex effects upon differential responding.

The present investigations examined the effects of three aspects of stimulus intensity upon the development of an auditory discrimination. Comparable experimental conditions obtained in each of the studies, excepting the manipulation of the variable under investigation.

After Pavlov developed the "method of contrasts", many procedures, devices, and response measures were invented to explore the stimulus control of differential responding (see Warden, Jenkins, and Warner, 1935; Woodworth and Schlosberg, 1954). It would appear that on occasion the technique itself has not only been a tool for research but has also defined the problems to be studied. This early literature contains generous amounts of information, much of which is difficult to interpret or impossible to integrate, and it sometimes produced irrelevant feuds arising out of the lack of standardized technique.

In contrast, modern free-operant research has been characterized by a relatively uniform situation and, until recently, almost total reli-

ance on response rate as the single dependent variable. However, the application of free-operant procedures to discrimination situations did not immediately produce a satisfactory and generally agreed upon methodology. In *The Behavior of Organisms* (1938), Skinner's original procedures involved brief S<sup>D</sup> presentations lasting only until a single response was emitted and reinforced. Rate was applicable only to S<sup>A</sup> (non-reinforced) conditions, where there was no restriction on the free emission of the response, making it impossible to apply a uniform analysis to the behavioral changes of the two components. Frick's (1948) modification of Skinner's methodology, by providing equal and alternating periods of S<sup>D</sup> and S<sup>A</sup>, was a significant improvement. However, the continuous reinforcement schedule maintained during S<sup>D</sup> periods confounded S<sup>D</sup> rate with eating time. Therefore, the rate analysis of discrimination formation was again limited to consideration of the non-reinforced responding emitted in the presence of the S<sup>A</sup> stimulus. Using the decline in S<sup>A</sup> rate as an index of discrimination formation yields a measure subject to distortion by the action of variables that may differentially affect S<sup>A</sup> and S<sup>D</sup> responding. Dinsmoor (1951), by providing intermittent reinforcement during S<sup>D</sup>, made it possible to extend the rate measure to an analysis of the behavioral changes occurring during the presentation of the positive stimulus. He wrote ". . . the provision of a measure comparable to that for S<sup>A</sup> might permit the calculation of a

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general index to the discrimination, based upon a comparison of the rates of responding under the two stimulus conditions." (p. 355)

Dinsmoor's technique resolved the analytic limitations of Skinner's approach, though his solution was not perfect. His intermittent reinforcement schedule was a one-minute fixed interval, producing a regularity in the  $S^D$ - $S^A$  cycle that provided a second source of discriminable stimuli. These data indicate that a temporal discrimination did develop.

Smith and Hoy (1954) removed the strict periodicity from their procedure in the following rather complex way: "Discrimination training was given during a series of 2-min. trials, 20 trials to an experimental session. Either  $S^D$  or  $S^A$  was present continuously during a 2-min. period. The sequence of  $S^D$  and  $S^A$  was determined randomly, subject to the restrictions that each appeared ten times in a session and that neither appeared more than three times in a row. During one  $S^D$  period three reinforcements were given; in three periods two were given; and in the remaining six periods, one was given. The order of these was randomly determined, as was the temporal point of reinforcement during the 2-min. period."

Smith and Hoy assess their own technique as follows: "It is felt that this randomizing of all factors except the correlation between reinforcement and light intensity makes it possible to eliminate all possible sources of discrimination except one. In addition, this technique allows continual observation of the rate of response in the presence of both positive and negative stimuli." (p. 260)

The rather obvious next step was taken independently by Herrick, Myers, and Korotkin (1959) and Pierrel (1958). In both cases the modifications involved uninterrupted free-operant procedures using several durations of the  $S^D$  and  $S^A$  periods and a variable-interval schedule during the  $S^D$  component. While the schedules employed in the latter two studies did not differ greatly in intermittency from that of the Smith and Hoy experiment, they did make more direct contact with the established reinforcement schedule literature, providing greater possibilities for systematic integration with other operant research.

If, in fact, this series of studies represents progress, we have not seen an extensive parametric study of discrimination beyond Frick's

now primitive procedures. Jenkins (1965) has noted this paucity of discrimination acquisition data and suggested the possibility that the methodology as it has developed does not possess the virtues claimed by Smith and Hoy and, indeed, is not suitable for evaluating the development of stimulus control. This charge was advanced because reinforcement delivery, as well as the intended discriminative stimuli, is available as a cue for differential responding. This procedural impurity is certainly present at a theoretical level. However, Pierrel and Blue's data (1967) indicate that cue functions arising from the reinforcement schedule are not of great behavioral significance in their situation. While some reinforcement schedules are discriminable and appear to interact with other stimuli to affect discriminative performance, not all schedules have this effect. Jenkins is correct that the range of reinforcement schedules available without serious confounding is limited, though his suggested alternative of a trial procedure with its inherent loss of continuous measurement is in itself somewhat restrictive.

While the now somewhat standard free-operant discrimination methodology is not beyond criticism, other procedures and measures are also subject to their own limitations (see Munn, 1933). In this context, such difficulties currently limit us to definitions of discrimination, which are restricted operationally to whatever procedure is employed. Thus, the course we have pursued has been an extended series of systematic studies, using coherent methodology, in which an array of variables is explored. This strategy seems most likely to reveal the inter-relationships of discrimination phenomena, advance the evaluation and development of related matters of technique, and will, with a little luck, even help to separate substantive from procedural matters. Such a systematic exploration of the effect of the three intensity variables on discrimination performance was the goal of the present investigation. The three variables examined were: the magnitude of the intensity difference between the stimuli in the presence of which responses were reinforced and were not reinforced; the intensity relationship between the two stimuli (the effect of  $S^D$  being more or less intense than  $S^A$ ); and, the location of the discriminanda along the intensity continuum.

In an analysis of discrimination behavior, Frick (1948) examined the question of whether the magnitude of the intensity difference between discriminanda affects acquisition. He trained five groups of rats to bar press, with the differences between the  $S^D$  and  $S^\Delta$  light intensity varied among them. The results showed that the number of responses that occurred in  $S^\Delta$  was inversely proportional to the magnitude of the  $S^D$ - $S^\Delta$  difference. Raben (1949) obtained similar results using a runway apparatus. These findings were also confirmed by Hanson (1959) over a portion of the wavelength continuum, using pigeons as subjects. He noted that once the  $S^D$ - $S^\Delta$  difference was increased to a certain magnitude (10 nm), further increases did not reduce the amount of training time required to attain a differential response criterion.

A study by the present investigators (Pierrel and Sherman, 1962) using 10, 20, and 30 db  $S^D$ - $S^\Delta$  auditory intensity differences yielded data that indicated that, beginning early in training,  $S^\Delta$  rates are inversely related to the magnitude of the difference between discriminanda. From the foregoing studies it would appear amply demonstrated that the magnitude of the  $S^D$ - $S^\Delta$  difference affects the rate of acquisition of differential responding.

In an attempt to isolate the effect of relative intensity, we used "counterpart pairs" of groups. A counterpart pair is one in which the discriminative stimuli are the same for the two groups, but the intensity relationship between  $S^D$  and  $S^\Delta$  is reversed. That is,  $S^D$  is the more intense stimulus for one group and  $S^\Delta$  is the more intense for the other. This arrangement permits examination of the effect of reversing the  $S^D$  and  $S^\Delta$  intensity relationship while the other experimental conditions (intensity difference and absolute intensity) remain the same.

In an earlier study, Sadowsky (1966) employed four sets of counterpart groups to investigate relative intensity effects as a function of absolute intensity at a single  $S^D$ - $S^\Delta$  intensity difference value (10 db). Each group was exposed to a 10-db discrimination in the range between 100 and 60 db (100-90, 90-100; 90-80, 80-90; *etc.*). When  $S^\Delta$  was the more intense stimulus and the discriminanda were located at the high-intensity end of the continuum, the rate of extinction in  $S^\Delta$  was retarded when compared to that of the counterpart. This ef-

fect was most marked for the groups with 100 or 90 db as  $S^\Delta$ , greatly reduced at 80 db, and absent at 70 db. The 70-60 *versus* 60-70 comparison showed no difference in the rate of acquisition of differential responding. No effect comparable to that shown in  $S^\Delta$  rates was observed in  $S^D$  responding. Further discussion of the continuum location variable will be deferred until the data on that topic are presented.

## METHOD

The acquisition of the bar press was studied using a simple two-valued multiple schedule. The study consisted of 14 experimental groups, plus a special group. The treatment of all experimental groups was similar except for the stimulus intensities employed as  $S^D$  and  $S^\Delta$ . The four animals in a given group were run simultaneously.

### *Subjects*

Sixty (15 groups of four each) male rats of a Specific Pathogen Free, Sprague-Dawley derived strain, purchased from Carworth, Inc., New City, New York, were between 114 and 174 days old at the start of experimentation. Free-feeding weights were determined over a period of five days after the rats arrived from the supplier. They were then provided with a maintenance diet that kept them at the predetermined weight until two weeks before experimentation. During these two weeks, they were reduced to 80% of free-feeding weight; their weights were then maintained at approximately 80% by the food reinforcers obtained during the experimental sessions. Water was available at all times in both the experimental and living cages.

### *Apparatus*

The four experimental enclosures were similarly constructed. These were shock-mounted refrigerator shells lined on all interior surfaces with Fiberglas sheets covered with Fiberglas cloth. The floor level was raised with Fiberglas blocks and a partition inserted to divide the area into experimental and equipment sections. The equipment section housed a pellet dispenser and a motor-driven retractable bar. A slot in the partition accommodated the tube from the feeder and the bar. The experimental section measured 13.5-in. wide by 23.5-

in. high by 15.0-in. deep (34.3 by 59.7 by 38.1 cm). The animal enclosure was constructed of stainless steel rod 0.5 in. (1.27 cm) apart mounted horizontally in a narrow Lucite frame. The dimensions were 8.0-in. wide, 5.8-in. high and 5.0-in. deep (20.3 by 14.7 by 12.7 cm). The bar was calibrated to operate a microswitch upon application of a force of 3 g (0.027 N). A stainless steel pan containing animal bedding was situated below the cage to collect feces and urine. Centered 7.5 in. (19.1 cm) above the cage was a high-frequency speaker. A sound-silenced ventilating unit provided a complete change of air in the boxes every 3 min. These arrangements provided a uniform sound field within an acoustically transparent animal enclosure. When a 4-kHz tone was present, point-to-point differences within the enclosure did not exceed 2 db. With the chamber closed and no stimulus sound input, the background level of mid-range frequency noise was about 30 db re 0.0002 microbar.

Ventilating, sound generating, scheduling, and response recording equipment were situated in an adjacent room. Sound stimuli were 4-kHz tones of fixed intensity generated by an oscillator. These were fed into a controlled rise/decay time switching preamplifier, through one of a set of fixed attenuators, and finally distributed to each of four similar amplifiers, yielding the same speaker output in all units. Any one of the bank of fixed attenuators could be selected by a stepping switch triggered by a punched tape interval programmer. The sound stimuli were presented as pulsed tones (1.5 sec on, 2.5 sec off). All intensity changes were scheduled to occur when the tone was in its "off" phase, eliminating the possibility of audible switching transients. Bar insertion at the start of the session and retraction at the end of session, level of sound stimuli and food reinforcement were scheduled by means of relay and timing circuits. Data were recorded on cumulative recorders, counters, and printout counters. A more detailed description of the equipment is available in Pierrel and Sherman (1960).

#### Procedure

Each of the 15 groups was run separately over successive 16-day periods. Except for the special group, all groups were treated as follows: *Day 1 (Bar-training)*. Each animal was

placed in the experimental enclosure and exposed to the sound intensity that was to serve as  $S^D$  during discrimination training. An FI 10-sec schedule was in effect until the animal had collected 50 reinforcements (pellets) for bar pressing. The reinforcement schedule was then changed to VI 2-min. Each animal remained in the enclosure until it had collected 75 to 80 pellets on the VI schedule and was then returned to the living cage. *Days 2 to 16 (Discrimination Training)*. Each animal was placed in an experimental chamber and was not removed again until the 15 days of discrimination training had been completed. Two 8-hr sessions were run daily from 1:00 PM to 9:00 PM, and from 1:00 AM to 9:00 AM. This yielded a total of 240 experimental hours. During the 4 hr between sessions, the sound was off and the bar retracted.

For each of the 14 experimental groups, two intensities of a 4-kHz tone were utilized as  $S^D$  and  $S^A$ . These were selected in such a way that the magnitude of the intensity difference between  $S^D$  and  $S^A$  was varied among groups. It was also possible to locate similar  $S^D$ - $S^A$  differences in various positions along the intensity continuum. Finally, each of the groups with any given intensity difference and continuum location had a counterpart. Counterpart groups are those having the same discriminanda, though the tone serving as the  $S^D$  intensity for one group served as the  $S^A$  for the other, and *vice versa*. These arrangements are shown in Table 1. Reference to the various groups will be made with respect to their  $S^D$  and  $S^A$  intensities. For example, the group trained with 100 db as  $S^D$  and 80 db as  $S^A$  is Group 100-80; the group trained with 60 db as  $S^D$  and 70 db as  $S^A$  is Group 60-70, and so on. Although the 40-db difference groups (60-100, 100-60) appear twice in the table for symmetry, these two groups were run only once.

Table 1

Plan of stimulus presentation for the 14 experimental groups.

Db Differ- ence	Sound Level in Decibels							
	A		B		C		D	
	$S^D$	$S^A$	$S^D$	$S^A$	$S^D$	$S^A$	$S^D$	$S^A$
10	60	70	70	60	100	90	90	100
20	60	80	80	60	100	80	80	100
30	60	90	90	60	100	70	70	100
40	60	100	100	60	100	60	60	100

All intensity levels are specified in terms of a 0-db reference level of 0.0002 microbar.

The  $S^D$  and  $S^A$  sound intensities were alternated throughout the session, with 50% of the session time devoted to each. The duration of any given intensity interval was 1, 2, or 3 min. The quasi-random order of alternation of stimulus interval lengths was taken from a Gellerman series designed to avoid simple alternation sequences. The mean inter-reinforcement interval during the  $S^D$  period was 2 min. The program of intervals was obtained by randomizing the terms of a geometric progression.

The conditions for the special group were the same as for the experimental groups, except that no single stimulus was ever uniquely associated with either periods of reinforcement availability or non-availability. Three stimulus intensities were employed: 60, 80, and 100 db. Each of the three stimuli was equally often associated with reinforcement periods (occurring temporally within the session at the same time as  $S^D$  intervals for the multiple schedule groups) and periods of extinction (the  $S^A$ s of the multiple schedule). The animals were run for 208 hr on this three-stimulus schedule and were then switched for the last 32 hr to a mixed schedule in which only 80 db was present. No other condition was changed.

*Data analysis.* In the data analysis to follow, a Discrimination Index (DI) is employed:  $DI = S^D / (S^D + S^A)$ . Thus, the Discrimination Index is the proportion of total responding that occurs during  $S^D$ . Changes in the  $S^D$  rate have relatively less effect on the DI when  $S^A$  rate is low in comparison to  $S^D$  rate. The numerical value of the DI representing equal response rates in the presence of  $S^D$  and  $S^A$  is 0.500. The index approaches a limit of 1.000 as responding during  $S^A$  extinguishes and  $S^D$  responding is maintained.

## RESULTS AND DISCUSSION

### *The Effect of $S^D$ - $S^A$ Difference on Discrimination Acquisition*

For the purpose of considering the  $S^D$ - $S^A$  intensity difference variable in the present study, the Discrimination Index data have been arranged in four sets corresponding to the arrangement of Table 1. Each set allows

comparison among the four groups having a common  $S^D$  or  $S^A$ . These findings are presented in Fig. 1.

The form of all of these DI functions is essentially that of a negatively accelerated positive function. There is little or no discrimination learning evident in the first 8 hr, as most of the curves start at or about 0.500 (50% of responding in  $S^D$ ; 50% in  $S^A$ ). The highest 8-hr point was achieved by the 100-60 group (0.549), which exhibited the highest DI values throughout the course of acquisition. For those groups with  $S^A$  as the relatively more-intense stimulus (panels A and D), the DI remains at close to 0.500 for up to 32 hr before showing a steady increase similar to the other curves.

In each of the four sets of groups, the 10-db animals (solid line) clearly developed less differential responding, or at least did so at a slower rate, than did their adjacent 20-db groups (dashed line). Among these comparisons, the slope is least steep and the final level is lowest for Groups 60-70, 70-60, and 100-90. The DIs from Group 90-100 describe a shallower curve, but reach a final level of discriminative performance comparable to that attained by the 80-100 group. The 20-db groups (dashed line) are inferior to their adjacent 30-db groups (dot-dash) in all but the 100-80 condition (panel C). The various 30- and 40-db comparisons exhibit overlapping final performance levels and only slight differences in slope, suggesting that a limit is being reached on the effectiveness of further increasing the size of the  $S^D$ - $S^A$  difference. This is in line with Hanson's observation that after a given wavelength separation between  $S^D$  and  $S^A$  was achieved, further increases in the difference did not increase the speed of discrimination acquisition. However, our data indicate that the limit of the effectiveness of this variable cannot be stated in terms of any given  $S^D$ - $S^A$  separation. Rather, a comparison of the four panels of Fig. 1 suggests different effective ranges and different limits of the  $S^D$ - $S^A$  intensity difference variable depending upon the value of the other two intensity variables simultaneously controlling discrimination performance. It is particularly clear in panel C that, while a 20-db intensity difference produces more rapid acquisition than does a 10-db difference, for this highest intensity  $S^D$  comparison only, increasing the  $S^D$ - $S^A$  differ-

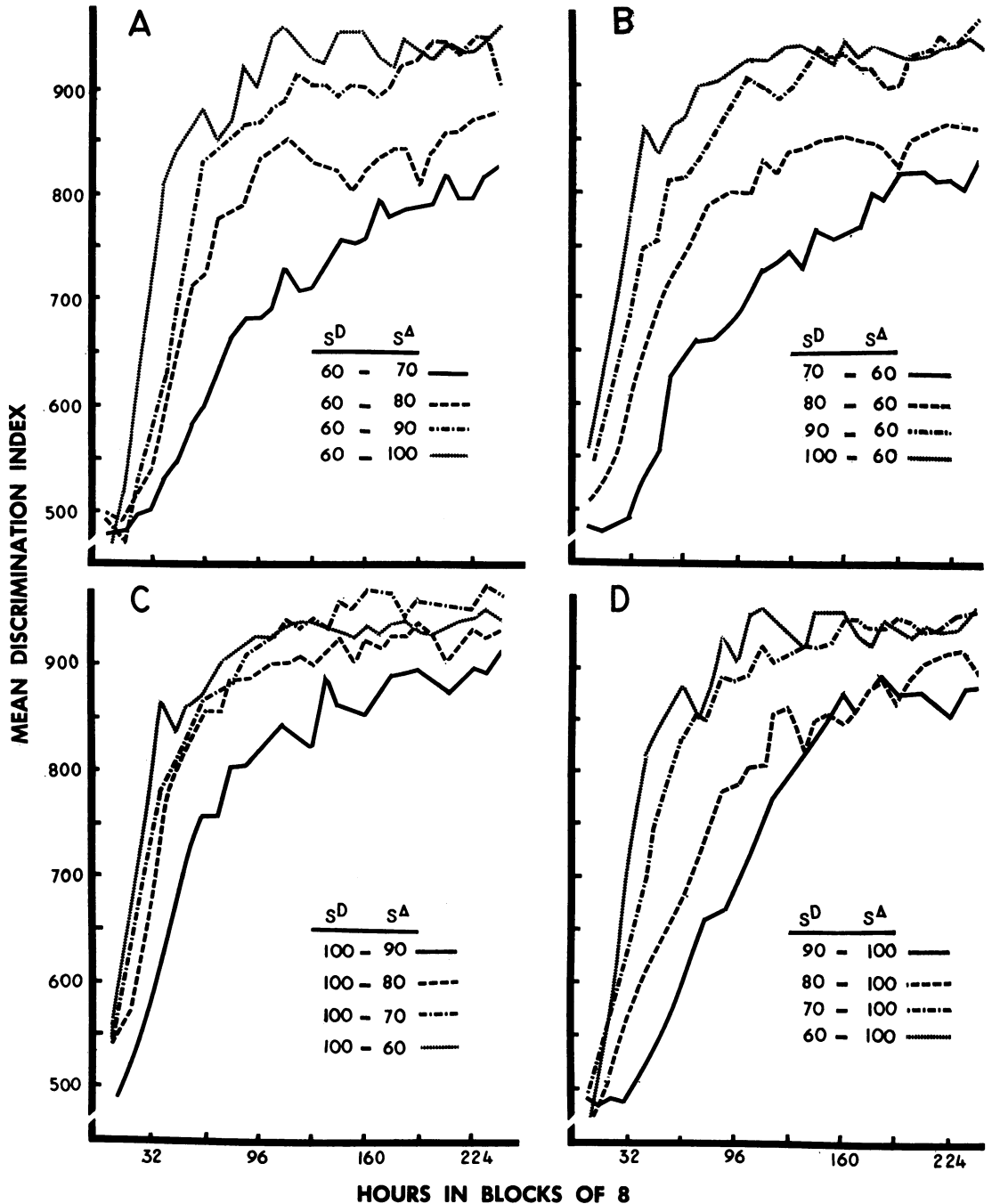


Fig. 1. Percentage of responding in S<sup>D</sup> (Discrimination Index) as a function of hours of training. Each point on each function represents the mean DI for four animals taken over eight consecutive hours.

ence beyond 20 db does not produce corresponding improvement in discrimination performance. A comparable limit is not seen at the lower extreme of our intensity difference dimension. Differential responding developed

for all animals in the 10-db groups, indicating that within the range employed, 10 db does not approach the magnitude of the difference limen at 4 kHz. Confirmation of this, as well as some indication of the reliability of the

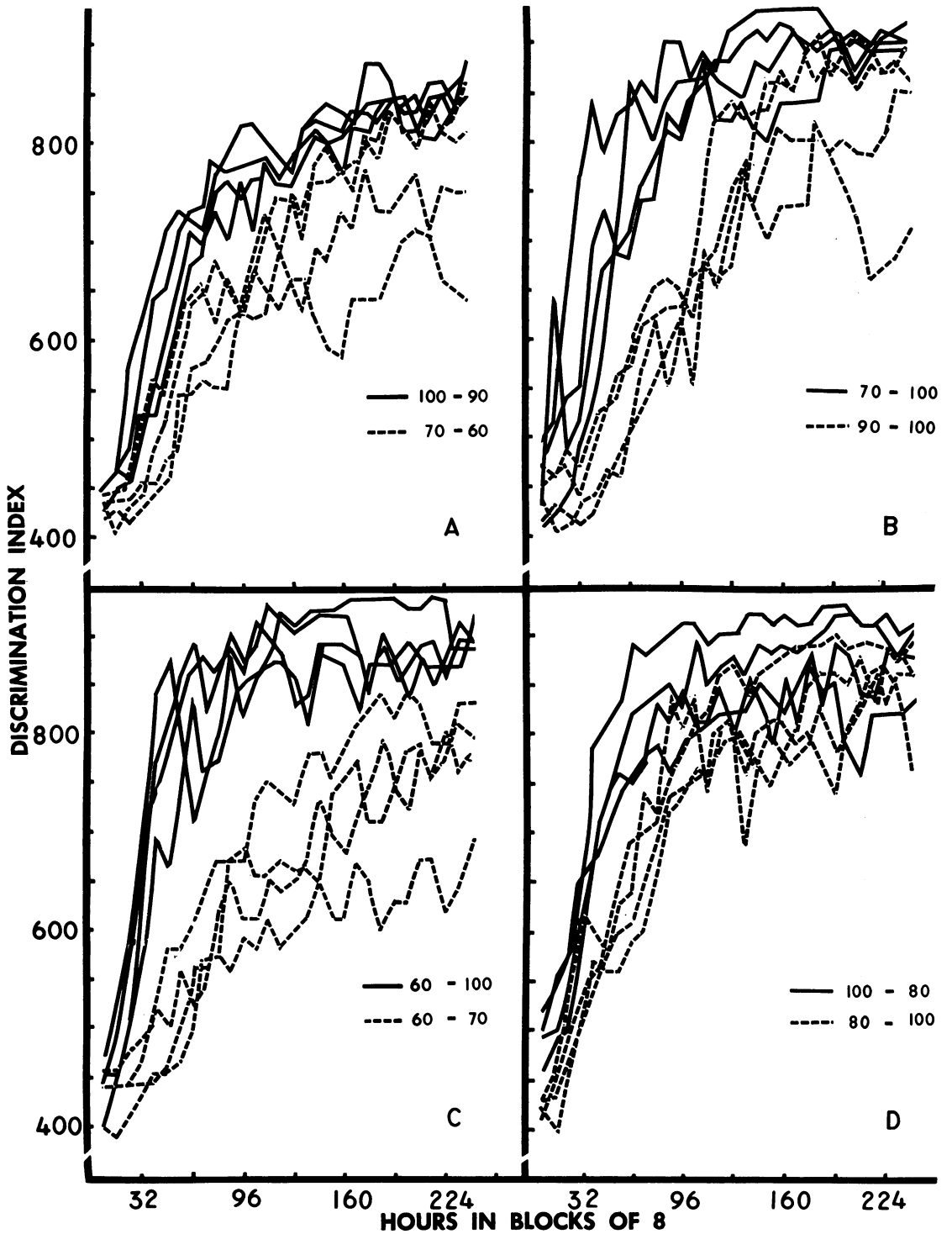


Fig. 2. Individual data. Percentage of responding in  $S^D$  (Discrimination Index) as a function of hours of training. Each point on each function represents the DI for a single animal taken across eight consecutive hours.

group differences seen in Fig. 1, can be gained by inspecting the individual data plotted in Fig. 2. The individual animals that make up

any given group have been plotted using the same texture. While the course of the individual curves is sometimes indistinguishable

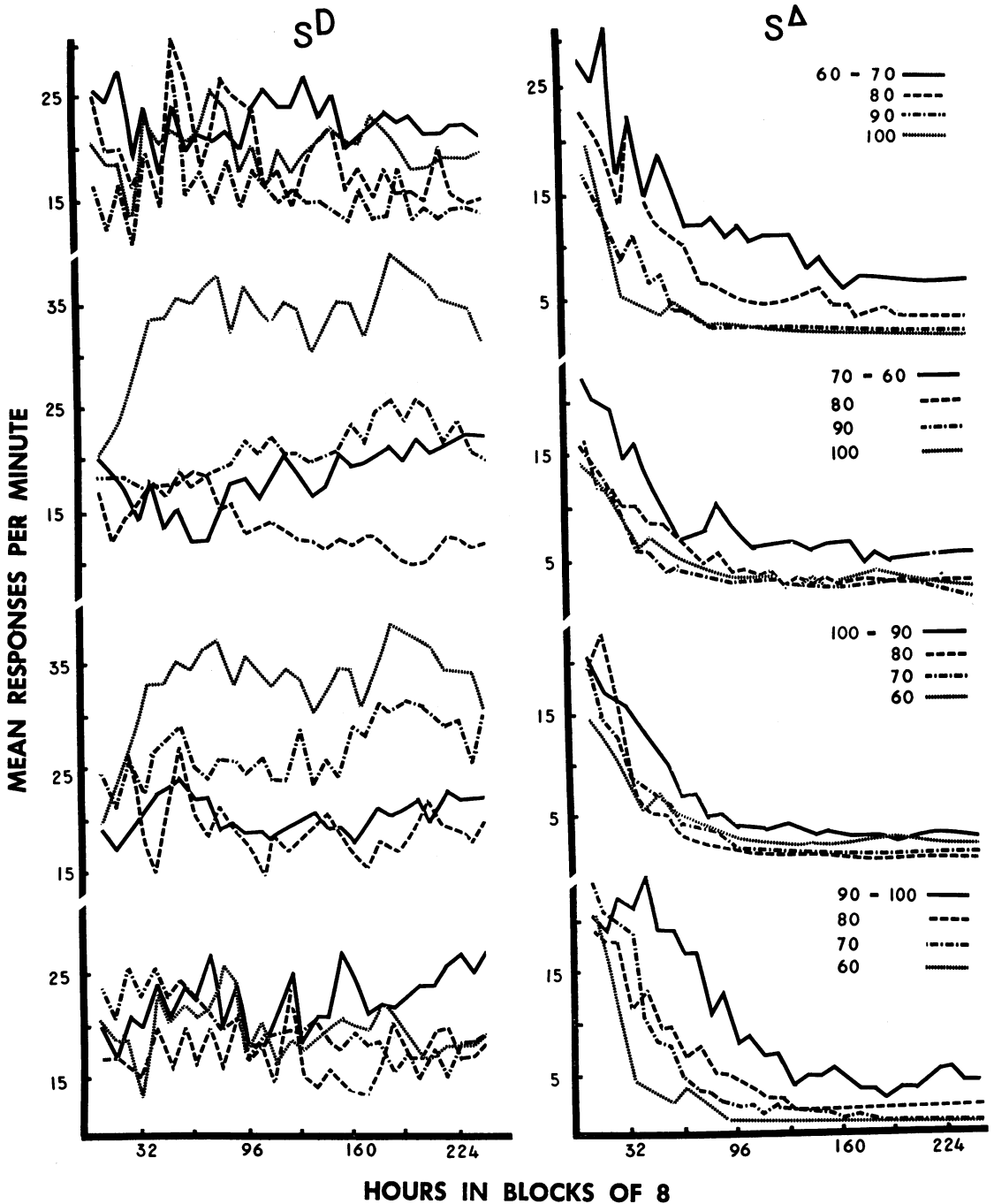


Fig. 3. *Left panel:* Mean  $S^D$  responses per minute for the animals in each group. Each point on each curve represents the mean of four animals taken across eight consecutive hours. *Right panel:* Mean  $S^\Delta$  response rates per minute for the animals in each group. Each point on each curve represents the mean of four animals taken across eight consecutive hours.



within a single group, the inter-group relationships are clear.

Changes in the  $S^D$  rate, changes in the  $S^A$  rate, or both. For example, an increase in DI may reflect an increase in  $S^D$  rate, a decrease in  $S^A$ , or both. Therefore, it is of interest to note any systematic changes that occur in response rates. The  $S^D$  and  $S^A$  rates as a function of hours are presented for each of the groups in Fig. 3. The groups are in the same sets for comparison as in Fig. 1. The  $S^D$  rates in the left panel show no systematic relationships and, in general, responding during  $S^D$  was relatively steady across training except for Group 100-60.  $S^A$  rate (right panel) declines fairly sharply for the first 40 to 96 hr. For the most part, the rate of decline and the fairly steady low rate level achieved in an inverse function of the  $S^D$ - $S^A$  difference. Again, excepting the 100-60 group, the differences in the DI functions essentially reflect differences in  $S^A$  rates.

*The Effect of Intensity Relationship Between  $S^D$  and  $S^A$  on Discrimination Acquisition*

Table 2 shows the comparisons that will be made in this section. These combinations of the data allow us to examine the effect of relative intensity, while at the same time examining its interactions with  $S^D$ - $S^A$  intensity difference and with absolute intensity.

Table 2

Group comparisons used to examine the effect of the  $S^D$  and  $S^A$  intensity relationship on discrimination acquisition.

Continuum Position	Decibel Difference			
	10 db	20 db	30 db	40 db
High-Intensity	100-90	100-80	100-70	
End	90-100	80-100	70-100	100-60 60-100
Low-Intensity	70-60	80-60	90-60	
End	60-70	60-80	60-90	

The groups in the top row of Table 2 are labelled as "High-Intensity End" because 100 db is either  $S^D$  or  $S^A$ . The distinction between high- and low-intensity ends becomes less meaningful as the  $S^D$ - $S^A$  differences become larger. Similarly, "Low-Intensity End" groups are those with 60 db as either  $S^D$  or  $S^A$ . Given

these distinctions, the 40-db groups logically complete both the high- and low-intensity sequences. We noted earlier that the differences between groups result largely from differences in  $S^A$  responding. Thus, the high-intensity groups provide a more direct comparison because the  $S^A$  intensity for those groups with the more intense  $S^A$  is held constant at 100 db.

Figure 4 presents curves for Groups 100-90 versus 90-100 and 100-80 versus 80-100. The DI functions are the upper curves in each set with the index values indicated on the left-most ordinate. Response rate is plotted below and scaled on the inside ordinate. The slope of the 100-90 DI curve is clearly steeper than that for 90-100. However, both groups achieved a similar level of final performance, the group differences disappearing after about 120 hr of training. The response rate data indicate that the difference is produced by the slower rate of extinction to the more intense  $S^A$  (100 db) because the  $S^D$  response rates are similar to one another. Stimulus intensity might be expected to influence  $S^D$  responding in such a way that Group 100-90 would emit a higher rate in  $S^D$  as well as a lower rate in  $S^A$ , as compared with its counterpart. It is possible that the variable-interval schedule may exercise such control as to determine  $S^D$  rate totally, precluding any intensity effects. We noted earlier that there was no systematic difference in  $S^D$  rate as a function of  $S^D$ - $S^A$  separation. Perhaps this consistency in  $S^D$  rate across groups (excepting 100-60) could also be attributed to the prepotency of VI schedule control.

The general effect initially reported by Sadowsky (1966) is confirmed here, but in his study the final performance level of the 90-100 group was lower than that of its counterpart; here, the difference gradually disappears. There is no contradiction between the two sets of data, however, since Sadowsky ran his groups for only 84 hr, and at least 120 hr of training were necessary to eliminate the group difference in the present study. The relative intensity effect, then, is marked early in acquisition but is gradually eliminated with prolonged training.

The 20-db high-intensity end comparison (100-80 versus 80-100) comprising the right portion of Fig. 4 displays results similar to those for the 10-db groups. Again the difference is produced by the slower rate of extinc-

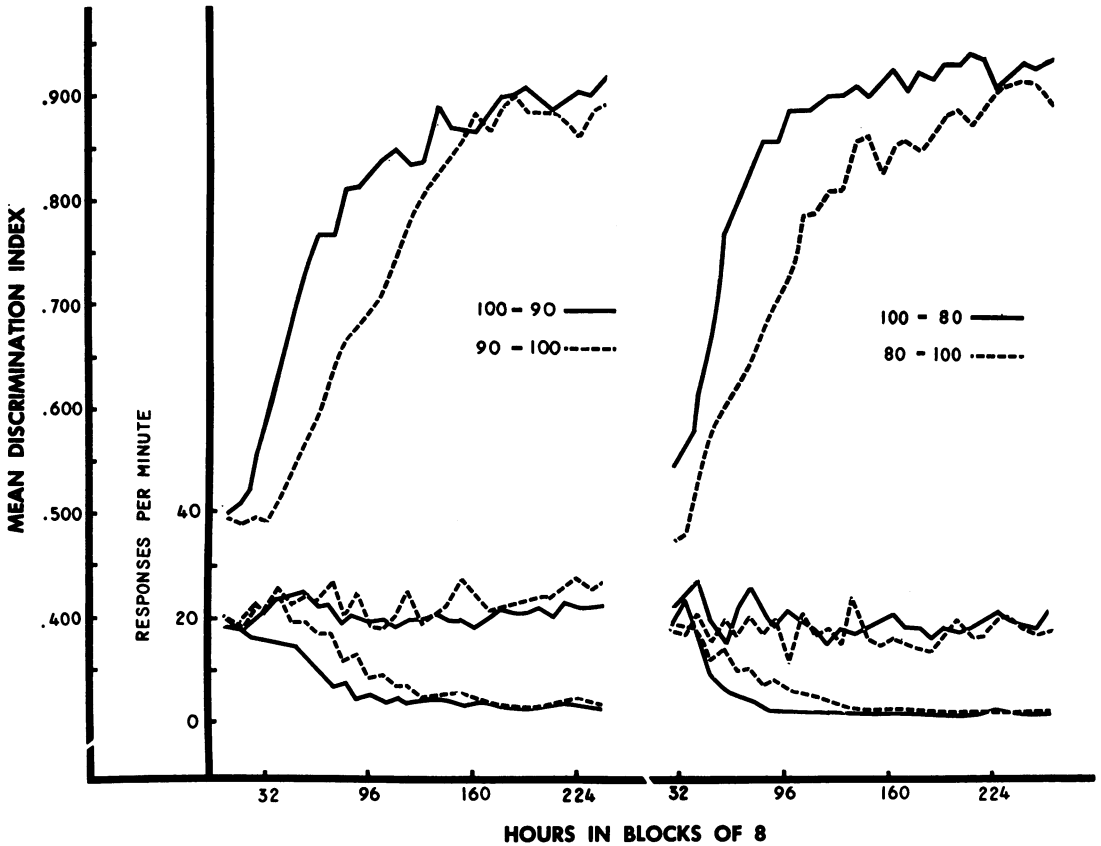


Fig. 4. *Upper sets of curves:* Percentage of responding in  $S^D$  as a function of hours of training. *Lower sets of curves:* Response rates in  $S^D$  and  $S^A$ . Each point on each curve represents the mean of four animals taken across eight consecutive hours.

tion to the more intense  $S^A$ , though here prolonged training eliminated the difference.  $S^D$  rates are essentially the same for the counterpart groups.

The two sets of curves in the right-hand portion of Fig. 5 display the DI functions for the 30-db high-intensity end comparison and the 40-db groups. The differences, early in training, between 100-70 and 70-100, and between 100-60 *versus* 60-100 are again a function of higher rates in  $S^A$  in the presence of the 100-db stimulus. There is no precise relationship between the magnitude and durability of the difference between counterpart pairs and the size of the  $S^D$ - $S^A$  separation. The difference between counterpart pairs for the 10- and 20-db comparisons is large and is maintained throughout most of the course of training, disappearing after about 120 to more than 200 hr. Smaller differences appear in the 30- and 40-db groups and are maintained for only 40 to 80 hr of training.

Completing the comparisons of Table 2, the curves for the low-intensity end groups appear as the three sets of curves in the left-hand portion of Fig. 5. The 70-60 *versus* 60-70 comparison (lowest set of curves) reveals no systematic differences during acquisition, confirming Sadowsky's (1966) observations with the same stimuli. However, looking at the other low-end groups, we find a slower rate of extinction to the more intense  $S^A$ , so that groups having 60 db as  $S^D$  (excluding 60-70) lag behind their counterparts in differential responding. At the low end of the continuum, as the  $S^D$ - $S^A$  intensity difference increases, the value of the more-intense  $S^A$  increases from 70 to 100 db. It is possible that the absolute intensity of  $S^A$  affects the rate of extinction. If both changes in the  $S^D$ - $S^A$  difference and the intensity of  $S^A$  affect the rate of extinction, then the two parametric manipulations are confounded under the conditions of stimulus placement that existed for the "Low-Intensity End" groups in Table 2.

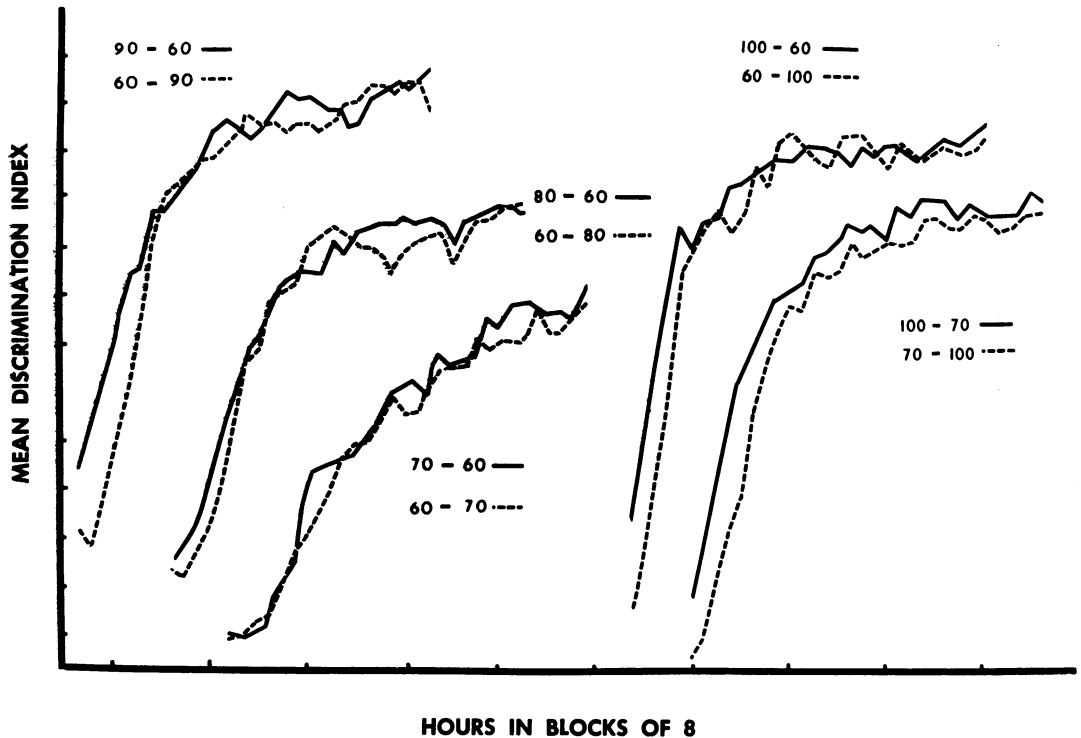


Fig. 5. Percentage of responding in  $S^D$  (Discrimination Index) as a function of hours of training. Each point on each function represents the mean DI for four animals taken across eight hours. These sets of curves have been offset on both axes to facilitate comparison.

In view of this possible unassessed interaction, a more direct examination of the effect of intensity was made. This examination involved the running of a special group. The conditions for this group were the same as for the 14 experimental groups in this study, except that no single stimulus was ever uniquely associated with either periods of reinforcement availability or non-availability (a type of mixed schedule; *cf.* Pierrel and Blue, 1967). Three stimulus intensities were employed: 60, 80, and 100 db. Each of the three stimuli was equally often associated with reinforcement periods (occurring temporally within the session at the same time as  $S^D$  intervals for the multiple schedule groups) and periods of extinction (the  $S^A$ s of the multiple schedule). The animals were run for 208 hr on this three-stimulus schedule, and were then switched for the last 32 hr to a mixed schedule in which only 80 db was present. No other condition was changed.

The results for this special group are shown in Fig. 6. The left side of the figure displays the DI curves by 8-hr blocks. The individual

functions are shown above and the mean curve below. The values plotted in these curves were calculated by summing responding across all periods of reinforcement availability regardless of intensity, and then dividing by the total response output. The break in the curves indicates the change from three intensities to one. There is no evidence of consistent change in response rate between the alternating periods of high and zero reinforcement probability. That is, variations in reinforcement density alone were not sufficient to control differential behavior under these conditions.

The right half of Fig. 6 partitions response rate as a function of stimulus intensity, regardless of whether or not that intensity was present during a high or zero reinforcement probability period. The upper curves show the performance of a representative animal, those below are the means in 8-hr blocks. During the 208 hr of three-stimulus training, all four animals showed consistently higher rates in the presence of 100 than for 80 or 60 db, whether 100 db was present during " $S^D$ " or

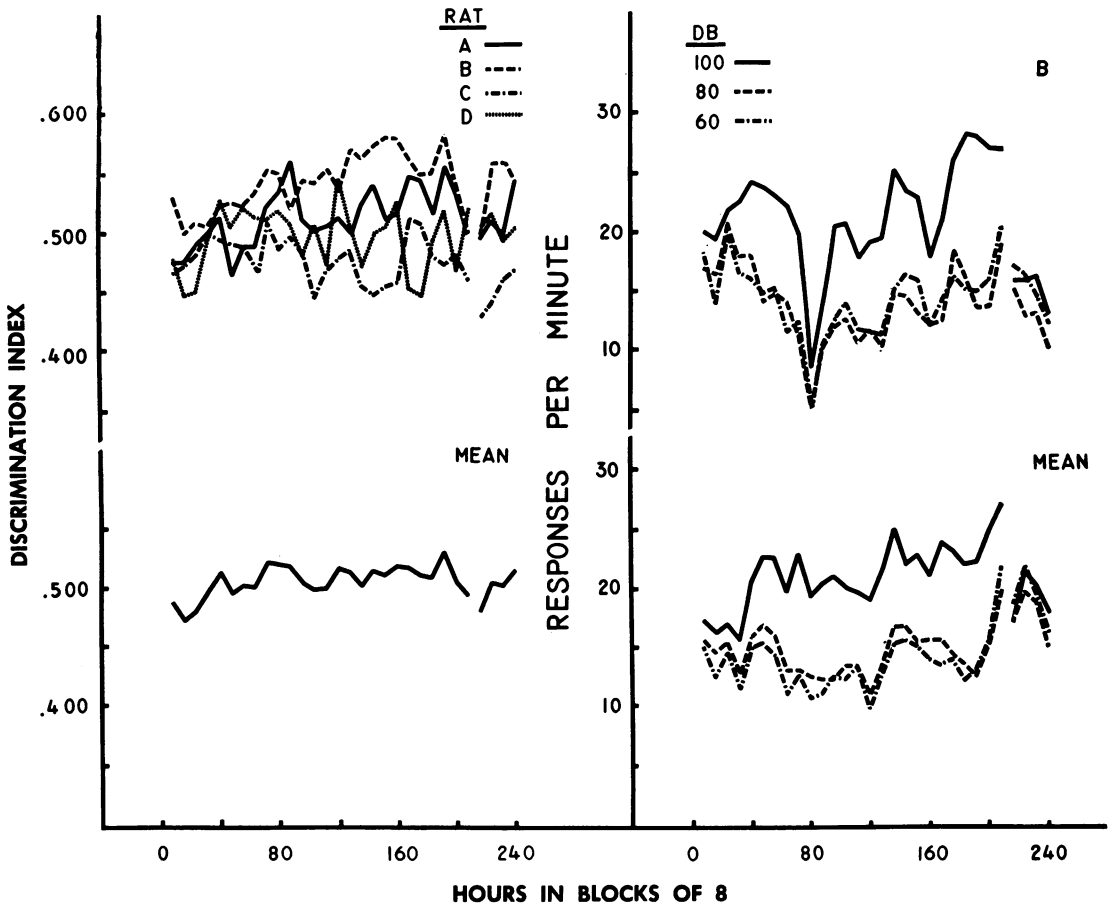


Fig. 6. Special Group Data. *Left-hand segment:* Percentage of responding in "S<sup>D</sup>" as a function of training. The upper curves represent individual animals, each point on each curve represents the DI value for eight consecutive hours. The lower curve is for the mean DI of the four animals. *Right-hand segment:* The upper curves show rate of responding as a function of training for Rat B. The lower set of curves represent the mean rates of responding for the four animals as a function of hours of training. Each point on each function represents the mean response rate in the presence of a given sound intensity as emitted across eight consecutive hours. The break in the curves indicates the change from three intensities to one (80 db).

"S<sup>A</sup>". This difference appeared during the first 8 hr of training and was maintained throughout. The mean curve shows a slightly higher rate for 80 than for 60 db, though there is considerable variability in the individual data. That the higher rate under 100 db was not an artifactual property of the stimulus sequence is demonstrated by the behavior of all the animals during the last 32 hr of training when only 80 db was present. Response rates were still partitioned as if the three stimuli were being alternated, but with only a single stimulus, the rates became similar across the session. These data provide a clear indication that the rate of an operant can be a direct function of stimulus intensity alone.

#### *The Effect of Continuum Location of S<sup>D</sup> and S<sup>A</sup> on Discrimination Acquisition*

Speculating on the manner in which absolute intensity affects discrimination acquisition, without information from the earlier sections of this study, one might assume that Group 100-90, for example, would exhibit more rapid acquisition than Group 70-60 because of a higher rate in the presence of the highest absolute intensity (100 db). Or, given that one knew that S<sup>D</sup> rates do not appear to vary systematically as a function of either intensity difference or relative intensity, a prediction might reflect an appreciation of the role of S<sup>A</sup> responding in the present type of

design. If higher  $S^A$  intensities result in slower extinction, higher rates in 90 versus 60 db would produce slower discrimination acquisition for the 100-90 group. This would indicate that the function of the absolute intensity variable was quite similar to that of the relative intensity variable. However, for the different multiple schedule groups, responding across the continuum does not vary in this fashion.

In order to investigate the effect of absolute intensity while systematically assessing the influence of the other two variables, the groups were arranged for study as shown in Table 3. The 40-db groups are omitted from these comparisons because their positions do not vary.

Table 3

Group comparisons used to examine the effect of continuum position on discrimination acquisition.

Intensity Relationship	Decibel Difference		
	10 db	20 db	30 db
More Intense $S^D$	100-90 70-60	100-80 80-60	100-70 90-60
More Intense $S^A$	90-100 60-70	80-100 60-80	70-100 60-90

The major question implicit in these comparisons is: holding relative intensity constant, do equal decibel differences produce equal degrees of differential responding?

The data from the groups with  $S^D$  as the relatively more-intense stimulus are examined first. The DI curves and response rate data for Groups 100-90 and 70-60 appear in the left panel of Fig. 7. The 100-90 group was earlier seen to exhibit more differential responding than the 90-100 group (Fig. 4). But there are two critical differences between these two types of comparison. First, the 100-90 versus 70-60 group difference is maintained throughout the course of discrimination training and shows little evidence of diminishing. The second difference is seen in the response-rate curves. As with the earlier comparisons, there is little differential effect of intensity on  $S^D$  rate (essentially none after about 80 hr of training), so that, as before, DI differences are a function of different  $S^A$  rates. But in the present case,  $S^A$  responding is maintained at a higher level in the presence of the less-intense  $S^A$  (60 versus 90 db). If there is any effect of intensity *per se*, it is not apparent under these conditions. This group difference is highly re-

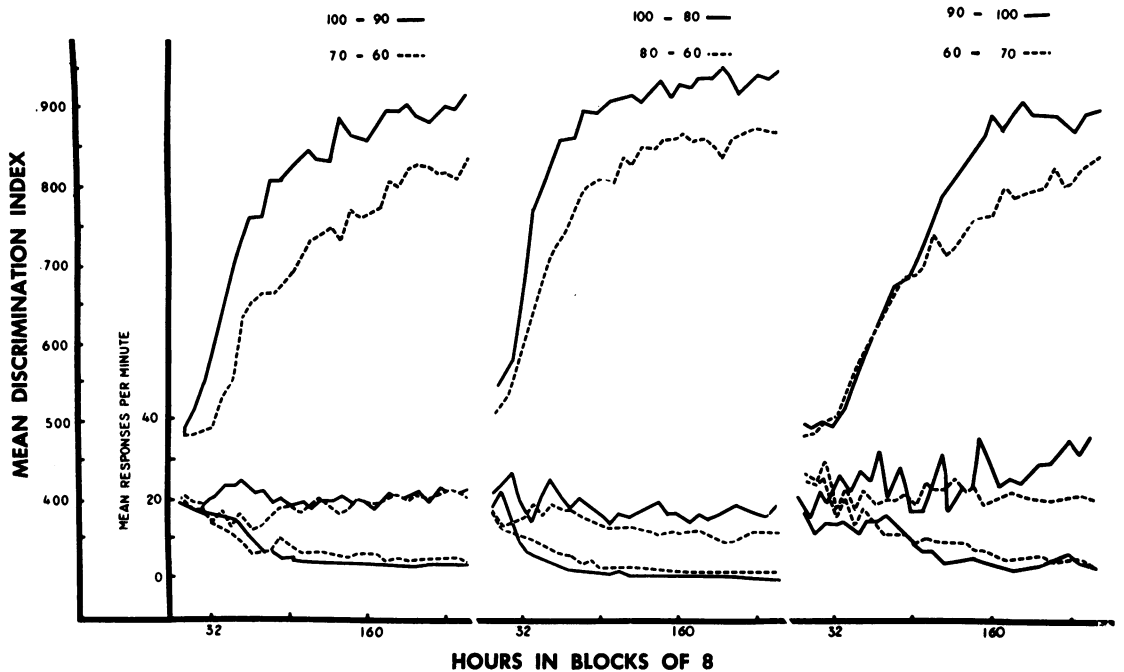


Fig. 7. Upper sets of curves: Percentage of responding in  $S^D$  as a function of hours of training. Lower sets of curves: Response rates in  $S^D$  and  $S^A$ . Each point on each curve represents the mean of four animals taken across eight consecutive hours.

liable, as can be seen from the individual DI curves plotted in panel A of Fig. 2. There is virtually no overlap between these two groups. The curve for the animal in Group 70-60 with the highest level of differential responding lies almost completely below the lowest animal in Group 100-90.

Figure 8 and the middle panel of Fig. 7 show the effect of increased  $S^D-S^A$  difference. For 20-db separations (100-80 *versus* 80-60) a similar but smaller group difference appears, and for the 30-db groups (100-70 *versus* 90-60; uppermost curves in Fig. 8) the difference is almost completely gone.

If we look now at the groups with  $S^A$  as the relatively more intense stimulus, we can see the interaction between the effect of relative intensity and absolute intensity. The right-hand panel of Fig. 7 displays the data for

Groups 90-100 and 60-70. There is no difference between their DI curves over approximately the first half of training, but after this point (about 120 hr), a separation similar to that seen throughout in the other two panels begins to appear, with the higher-intensity group exhibiting the higher DIs. It will be remembered that in comparing Groups 100-90 and 90-100, the effect of the intensity relationship disappeared after about 120 hr, and that there was no difference at any time between Groups 70-60 and 60-70. Up to the 120-hr point, there appear to be interacting effects of relative intensity (slowing extinction for Group 90-100, but not affecting Group 60-70) and continuum location (facilitating 90-100 but not 60-70). These effects cancel one another. Sadlowsky (1966) proposed a similar interaction to account for his findings. The ef-

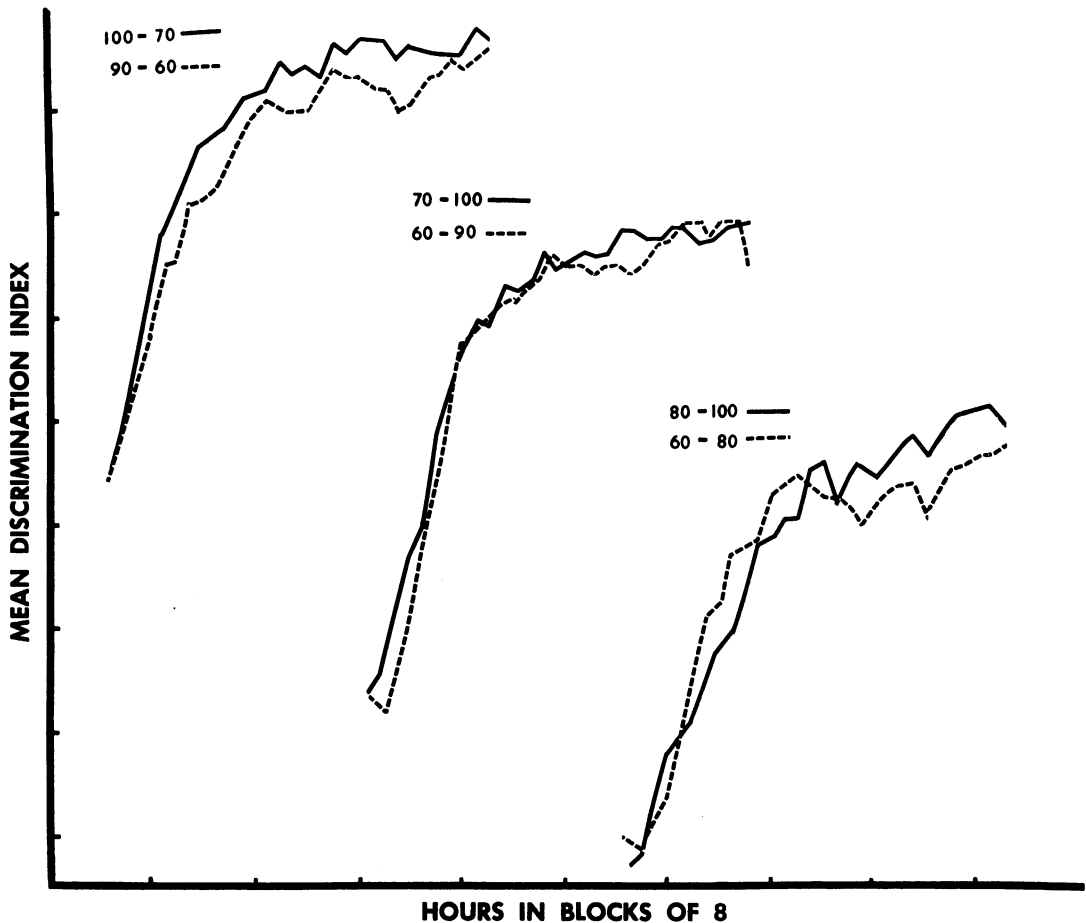


Fig. 8. Percentage of responding in  $S^D$  (Discrimination Index) as a function of hours of training. Each point on each function represents the mean DI for four animals taken across eight hours. These sets of curves have been offset on both axes to facilitate comparison.

fect of intensity relationship is temporary, but the influence of continuum location is not. Therefore, the action of this latter variable appears only after considerable training.

The other two sets of curves in Fig. 8 complete the analysis. A small difference favoring Group 80-100 *versus* 60-80 begins to appear late in training. As seen in Fig. 4, the effect of intensity relationship for the 20-db high-intensity groups is maintained almost throughout the course of training. Here again, when relative intensity effects disappear, the effect of absolute intensity becomes apparent. The 30-db group comparison (70-100 *versus* 60-90) yields virtually no difference. Apparently the stimuli involved in the 30-db comparisons, overlapping almost completely as they do, are too similar in location to reveal the effect of continuum position in a reliable fashion.

## GENERAL DISCUSSION

### *On the Effect of $S^D$ - $S^A$ Difference*

In comparison with a number of recent discrimination studies involving complex, multi-dimensional stimuli, the present investigation examined a number of parameters of a relatively simple physical continuum, that of auditory intensity. Despite the unidimensionality and simplicity of the stimuli employed, an unexpected complexity and richness of effects upon differential responding was observed. Each of the three variables investigated generates orderly functional relationships. It was previously well established that increases in discriminanda difference affect the rate of acquisition of differential responding. However, the systematic manipulation of this variable in the present study permits a more accurate estimation of the importance of  $S^D$ - $S^A$  difference under the several conditions of intensity relationship between the discriminanda and position on the continuum. Besides its intrinsic interest and importance as a step towards an increasingly precise empirical statement of the acquisition process, this information should be of benefit to an experimenter who is interested in rapidly establishing a baseline of discriminative responding and who chooses to employ some variation of a multiple schedule procedure as his experimental technique. Based on the present results and on an earlier study, the following conditions should be observed in order to develop differential re-

sponding relatively quickly: the magnitude of the separation between  $S^D$  and  $S^A$  should be relatively large;  $S^D$  should be the more intense stimulus and should be located at the high-intensity end of the continuum; exposure to  $S^A$  should be about three times that to  $S^D$  (Sherman, Hegge, and Pierrel, 1964); and a high rate of responding should be controlled in  $S^D$  by a schedule of reinforcement such as variable interval. These conditions minimize the influence of other variables that have been shown to limit or delay discrimination acquisition.

### *On Data Related to Behavioral Contrast*

The left-hand panel of Fig. 3 showed that the rate in  $S^D$  was relatively constant during training for all groups except 100-60. The  $S^D$  curve for this group is seen most clearly in the functions plotted just below the top set. Initially, as is true of the other groups, the rate was approximately 20 responses per minute. However, this group's rate rose steadily over the first 88 hr of training to nearly 40 responses per minute. This increase in  $S^D$  responding with concurrent decreases in  $S^A$  rate during discrimination training suggests what Reynolds (1961) and others have termed "behavioral contrast". Reynolds has proposed that differential reinforcement density is the variable controlling contrast effects. Alternatively, Terrace has asserted: ". . . the suppression of the rate of responding . . . in the presence of (one of) two alternating stimuli, seems to be a sufficient condition to produce contrast" (1966, p. 322). We clearly have  $S^A$  response rate reduction ("suppression") for all 14 experimental groups (see right panel of Fig. 3), but only for Group 100-60 was there a reciprocal rise in  $S^D$  rate. An opportunity to replicate Group 100-60 occurred during the completion of this study, and again the rate increase in  $S^D$  from about 20 to 40 responses was observed. Terrace's formulation might be extended to take into account the speed of discrimination acquisition. Group 100-60 showed the most rapid acquisition, initially, as a function of the most rapid rate of  $S^A$  extinction (the high rate of about 20 responses per hour during the first hour decreased to a mean of 14.3 for the total 8 hr). Perhaps contrast occurs, not merely because responding is reduced in the presence of one stimulus, but rather *when that reduction proceeds at or*

beyond some critical rate. The rather gradual response reduction seen in most of our groups may not "activate the mechanism" whose operation is described as contrast.

#### *On the Effect of Intensity Relationship*

By employing the counterpart pair design, which manipulates the intensity relationship between the discriminanda, we demonstrated that, under some conditions, the intensity of the  $S^A$  affects the rate of extinction. Concerning the general question of how responding is affected by intensity, *per se*, an early recognition of the influence of the amount of exteroceptive stimulus energy on some response system was the formulation of the relationship between intensity and reaction time. Response latency was found to be an inverse function of stimulus intensity over a considerable range (Woodworth and Schlosberg, 1954). Hull (1952) dealt with this relationship in his revised set of postulates, calling it "stimulus intensity dynamism". He asserted that response "strength", as measured by latency, amplitude, or frequency of occurrence, is a direct function of stimulus intensity. This effect has been particularly well demonstrated in respondent conditioning experiments. In these, the amplitude of either the conditional or unconditional galvanic skin response, for example, has been shown to be correlated with stimulus magnitude (Hovland, 1937; Hovland and Riesen, 1940). Gray (1965) reviewed the literature dealing with the question of stimulus intensity dynamism. He concluded that dynamism occurs only when a stimulus is established either as an  $S^D$  or as a CS. It is also his contention that dynamism effects are most predictable if the stimulus is defined not in terms of absolute physical intensity, but rather in terms of the "degree of contrast" between various levels of stimulation.

We addressed this issue of how responding is affected by stimulus intensity in an earlier study (Hegge, Pierrel, Sherman, and Sadowky, 1965). In that experiment, rats were trained to bar press on a VI 1-min schedule in the presence of a 4-kHz tone. The intensity of this tone changed every 1 to 3 min. Nine intensities, ranging between 60 and 100 db in 5-db intervals, were used. When response totals were partitioned as a function of the intensity level present, no systematic differences were observed. For this type of design then, there

was no relationship between stimulus intensity and response strength, as measured by rate of emission. There are, however, two clear differences between the design of this earlier experiment and that of the present investigation. In the previous study, the animals were exposed to many relatively small stimulus changes, since the nine stimuli used were spaced at 5-db intervals. Probably more important, though, no long periods of extinction alternated with a VI schedule. The special group in this study was run in an effort to assess the effects of these design differences on the development of the rate-intensity relationship. Three stimuli were employed and reinforcement availability was equivalent under every intensity. The results indicated that rate of responding in the presence of the highest intensity (100 db) was consistently higher than in the presence of 60 or 80 db. It should be noted that these data also bear on the problem of defining "stimulus control". Stimulus control is usually measured in terms of differential responding, and if we examine only the DI curves for this group (left panel, Fig. 6), no stimulus control is evident. It is clear, however, that differential responding does occur as a function of stimulus intensity, even though the intensities employed were not related to the differential reinforcement contingencies. The animals reacted with an increase in responding each time 100 db was presented. As indicated above, Hegge *et al.* (1965) found no intensity effect. There appear to be two major differences between these studies. First, the smallest stimulus change involved here was 20 db, whereas a preponderance of 5, 10, and 15 db changes were employed in the Hegge experiment. Secondly, extinction was not alternated with their VI schedule. Despite the fact that the behavior of our special group of animals was uncorrelated with the reinforcement schedules, the existence of the alternating periods of reinforcement availability and extinction might somehow be responsible for the development of the intensity effect.

#### *On the Parametric Limits of the Effect of Intensity Relationship*

Considerable controversy has surrounded the issue of whether or not operant discriminated responding is affected by the magnitude of the intensity of the discriminanda employed. The data from our special group



make it clear that intensity, *per se*, can affect response rate, and the conditions of discrimination training under which this effect can be measured have been more thoroughly specified in this study than previously. That is, this intensity effect is seen most clearly as slower extinction in  $S^A$  responding, relative to the appropriate counterpart group, where  $S^A$  is more intense than  $S^D$  and is positioned at the high-intensity end of the stimulus continuum. Since the effect is eliminated once a group has obtained a fairly stable level of differential responding, the relative retardation of extinction is most prolonged in those groups having a small  $S^D$ - $S^A$  difference (20 db or less). It is now obvious why no such intensity effect was reported in certain earlier work from our laboratory (Pierrel, 1958; Pierrel and Sherman, 1960). In these studies we used a large  $S^D$ - $S^A$  difference or a non-optimal continuum placement of the discriminanda. In addition, in these studies there was three times as much exposure to the  $S^A$  stimulus as to the  $S^D$  stimulus, promoting a more rapid approach to asymptote. Any relative intensity effect that may have occurred must have been minimal and transitory.

#### *On the Nature of "Dynamism"*

As noted earlier, intensity effects have been observed in other experimental situations, and an attempt has been made by Gray (1965) to integrate the results of these studies and to suggest a mechanism to account for these effects. Following Hull, he refers to "stimulus intensity dynamism" and concluded that this effect is best explained in terms of a "contrast hypothesis". Gray was impressed by a number of studies that indicated that response strength was related to the magnitude of the stimulus change, irrespective of the direction of that change, rather than to the actual physical intensity of the various stimuli used. Gray related this type of finding to the Perkins-Logan interpretation of dynamism in terms of the "generalization of inhibition" and suggested that stimulus intensity dynamism is merely a "special case of generalization or discrimination behavior, rather than a phenomenon *sui generis*" (1965, p. 193), that is, an effect of intensity *per se*.

Gray, however, included in his review some negative evidence: "A study which the contrast hypothesis has difficulty in handling is

one by Spence (reported in Hull, 1947), who found that rats made fewer errors in choice of runway when a white one was the positive stimulus and a black one was the negative stimulus than when the signal values of the black and white runways were reversed. In this situation the contrast between positive and negative stimuli is obviously the same whether black or white is reinforced." (p. 185) In other words, Spence made use of the counterpart pair design and found an intensity effect. Gray failed to appreciate the importance of Spence's observation, since at that time it had not been confirmed. However, given the several replications of this counterpart pair effect in both Sadowsky's findings and those of the present study, little doubt remains as to the existence of a "*sui generis*" intensity effect. We would not deny the importance of the "degree of contrast" between discriminative stimuli, since, in many instances, its effects are closely related, if not identical to those of  $S^D$ - $S^A$  difference. However, this variable alone cannot account for all of the rate-modulating properties of stimulus intensity.

#### *On the Effect of Continuum Location*

Decibel differences at the high-intensity end of the continuum (around 90 to 100 db, see Fig. 7) generate and maintain higher levels of differential responding than do equal decibel differences at the low-intensity end (around 60 to 70 db). The persistence of this continuum location effect over the prolonged training period of 240 hr suggests that, as opposed to the intensity relationship effect, which "adapts" after a longer or shorter time, we are dealing with some psychophysical property of the discriminative stimuli which places a limit on the level of differential control that can be exerted by a given discriminative stimulus pair. In other words, we may be measuring behavior directly related to the "psychological space" between stimuli or the scalar properties of "loudness", the psychological counterpart of physical auditory intensity.

There is no experimentally determined psychological loudness scale for rats. From human psychophysical work, there are two major approaches from which we may borrow some concepts. Historically, precedence is given to Fechner's proposition that psychological sensation is linearly related to the logarithm of stimulus intensity. Since decibel

scales are logarithmic, Fechner's Law predicts that equal decibel differences should promote equal rates of discrimination acquisition. This is clearly not true in every case for our experimental design. A more recent formulation by S. S. Stevens provides an alternative prediction. Stevens proposes that sensation is related to stimulus intensity raised to some power, which would mean that a logarithmic measure of sensation is linearly related to the logarithm of stimulus intensity. For the auditory intensity dimension, Stevens and Davis (as reported by Licklider, 1951) constructed a psychological scale for loudness which conforms to the power law assumptions and is called the "sone" scale.

A sone is the loudness of a 1-kHz tone at 40 db and is the arbitrary unit of this scale. If we select from Stevens and Davis' data the sone value for 100 and 90 db *versus* 70 and 60 db, we find that a 4-kHz tone at 100 db has a loudness value of about 109 sones and at 90 db about 82 sones, or a difference of 27 loudness units. The comparable figures for 70 and 60 db are 59 and 53 sones, respectively, or a difference of only six loudness units. Clearly these data provide a basis for the prediction of the group differences observed in the present study, and suggest that the loudness scale for rats may be based on the power law formulation of Stevens rather than the logarithmic law of Fechner.

Regardless of one's theoretical position, the data show that when equal  $S^D$ - $S^A$  decibel differences are selected from the high and low extremes of the intensity continuum, quite different levels of differential responding occur. This result indicates that the traditional reliance upon the logarithmic spacing of auditory stimuli, while of great convenience, is at best a partial solution to scaling psychophysical distances. This finding also strengthens the argument that precision in predicting behavior requires the construction of psychological scales of measurement corresponding to the physical continua employed in any given experiment. Shepard (1965) has pointed out that this is of particular importance when choices between competing theoretical deductions must be made.

We have devoted considerable space to discussing the manner in which the three intensity variables studied interact. Investigators of the "loudness" of tones for rats (and presum-

ably other organisms) would be well advised to employ experimental techniques that allow for an assessment of other effects of stimulus intensity not related to its scalar properties. In particular, any changes in responding that might be attributable to "stimulus intensity dynamism" must be controlled for, either by appropriate selection of stimuli, or prolonged training sufficient to eliminate what would be, in the context of psychophysical scaling, artifactual intensity effects.

## REFERENCES

- Dinsmoor, J. A. The effect of periodic reinforcement of bar-pressing in the presence of a discriminative stimulus. *Journal of Comparative and Physiological Psychology*, 1951, **44**, 354-361.
- Frick, F. C. An analysis of an operant discrimination. *Journal of Psychology*, 1948, **26**, 93-123.
- Gray, J. A. Stimulus intensity dynamism. *Psychological Bulletin*, 1965, **63**, 180-196.
- Hanson, H. M. Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, 1959, **58**, 321-333.
- Hegge, F., Pierrel, R., Sherman, J. G., and Sadowsky, S. Non-differential conditioning of operant responding across a sound intensity continuum. *Psychonomic Science*, 1965, **2**, 11-12.
- Herrick, R. M., Myers, J. L., and Korotkin, A. L. Changes in  $S^D$  and  $S^A$  rates during the development of an operant discrimination. *Journal of Comparative and Physiological Psychology*, 1959, **52**, 359-363.
- Hovland, C. I. The generalization of conditioned responses: II. The sensory generalization of conditioned responses with varying intensities of tone. *Journal of Genetic Psychology*, 1937, **51**, 279-291.
- Hovland, C. I. and Riesen, A. H. Magnitude of galvanic and vasomotor responses as a function of stimulus intensity. *Journal of General Psychology*, 1940, **23**, 103-121.
- Hull, C. L. The problem of primary stimulus generalization. *Psychological Review*, 1947, **54**, 120-134.
- Hull, C. L. *A behavior system*. New Haven: Yale University Press, 1952.
- Jenkins, H. M. Measurement of stimulus control during discriminative operant conditioning. *Psychological Bulletin*, 1965, **64**, 365-376.
- Licklider, J. C. R. Basic correlates of the auditory stimulus. In S. S. Stevens (Ed.), *Handbook of Experimental Psychology*. New York: Wiley, 1951. Pp. 985-1039.
- Munn, N. L. *An introduction to animal psychology: the behavior of the rat*. Boston: Houghton Mifflin, 1933.
- Pierrel, R. A generalization gradient for auditory intensity in the rat. *Journal of Experimental Analysis of Behavior*, 1958, **1**, 303-313.
- Pierrel, R. and Blue, S. Antecedent reinforcement contingencies in the stimulus control of an auditory discrimination. *Journal of Experimental Analysis of Behavior*, 1967, **10**, 545-550.

- Pierrel, R. and Sherman, J. G. Generalization of auditory intensity following discrimination training. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 313-322.
- Pierrel, R. and Sherman, J. G. Generalization and discrimination as a function of the  $S^D$ - $S^+$  difference. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 57-72.
- Raben, M. W. The white rat's discrimination of differences of illumination as measured by a running response. *Journal of Comparative and Physiological Psychology*, 1949, 42, 254-272.
- Reynolds, G. S. An analysis of interactions in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 107-117.
- Sadowsky, S. Discrimination learning as a function of stimulus location along an auditory intensity continuum. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 219-225.
- Shepard, R. N. Approximations to uniform gradients of generalization by monotone transformations of scale. In D. I. Mostofsky (Ed.), *Stimulus generalization*. Stanford: Stanford University Press, 1965. Pp. 94-110.
- Sherman, J. G., Hegge, F. W., and Pierrel, R. Discrimination formation as related to the amount of  $S^+$  training. *Psychonomic Science*, 1964, 1, 43-44.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Smith, J. J., Jr. and Hoy, W. J. Rate of responses during operant discrimination. *Journal of Experimental Psychology*, 1954, 48, 259-264.
- Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research*. New York: Appleton-Century-Crofts, 1966. Pp. 271-344.
- Warden, C. J., Jenkins, T. N., and Warner, L. H. *Comparative psychology*, Vols. I-III. New York: Ronald, 1935.
- Woodworth, R. S. and Schlosberg, H. *Experimental psychology*. New York: Holt, 1954.

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