*THE EFFECTS OF VARYING THE DISTRIBUTION OF
GENERALIZATION STIMULI WITHIN A CONSTANT
RANGE UPON THE BISECTION OF A SOUND-
INTENSITY INTERVAL BY RATS¹*

THOMAS G. RASLEAR

BROWN UNIVERSITY

Two male, albino rats were trained on a two-valued, self-paced, discrete-trials auditory discrimination. In the presence of a high-intensity stimulus (90 decibels SPL, 4 kiloHertz), response A was reinforced; in the presence of a low-intensity stimulus (50 decibels SPL, 4 kiloHertz), response B was reinforced. When discrimination performance was asymptotic, stimuli intermediate in intensity were presented with the training stimuli in a maintained generalization paradigm. Generalization gradients were derived from the relative frequencies of response A in the presence of each stimulus. A relative frequency of 0.50 was then determined and used as the bisection point of the intensity interval defined by the 90- and 50-decibel stimuli. The bisection point varied with the distribution of the stimuli presented in generalization. This effect was similar to context effects seen in human psychophysics.

There have been numerous successful efforts to adapt human psychophysical methods to animal experiments. However, relatively few have employed stimulus generalization procedures in determining sensory distances and magnitude scaling in animals. Boakes (1969a, b) described such a stimulus generalization technique. Pigeons were trained to perform response A in the presence of stimulus A, and to perform response B in the presence of stimulus B. Then, stimuli of intermediate intensity were presented with the training stimuli, and the relative frequency of response A to each of the stimuli was computed to yield a generalization gradient. The stimulus value that produced a 0.50 relative frequency of response defined the bisection point of the interval bounded by stimulus A and stimulus B. Theoretically, the bisection point defines equal sensory distances, and also may be used to determine the relationship between response and physical stimulus scales (Fagot, 1963; Stevens, 1955).

The application of fractionation techniques in animal studies poses problems analogous to those in human psychophysics. Human data obtained using these techniques often show

"context effects". These are changes in response probability not attributable to stimulus magnitude, but dependent upon other aspects of the procedure. Helson (1964) indicated that the major factors known to produce context effects include the method employed, frequency of presentation and number of stimuli, spatial and temporal spacing of stimuli, amount of practice, and stimulus range. Since each of these factors has been shown to influence human psychophysical data, they may also be operating in experiments utilizing animals.

Boakes (1969b) tested for two context effects common in human psychophysics. These were a sequential effect, in which test trial performance was influenced by the stimulus presented on the preceding trial; and context effects, produced by the spacing of test stimuli along the continuum. Pigeons were used in these experiments in a self-paced, two-choice, discrete-trials paradigm in which light intensity was varied. To test for sequential effects, test trials following low-intensity training stimulus trials were separated from test trials following high-intensity training trials. Given that there was a sequential effect, the generalization gradients constructed from the partitioned trials should have been displaced from each other. However, Boakes' (1969b) data showed no evidence of this. The test for context effects arising from differential spacing of test stimuli used two groups of pigeons. One group was tested in generalization with eight light intensities,

¹This investigation was carried out while the author was a United States Public Health Service Pre-doctoral Research Fellow. The author wishes to acknowledge the constructive criticism and suggestions of Rosemary Pierrel Sorrentino. Reprints may be obtained from the author, Hunter Laboratory of Psychology, Brown University, Providence, Rhode Island 02912.

whereas the other group was tested with five intensities in the same range. The group with the smaller number of stimuli had a higher bisection point than the other group, though the difference was not statistically significant.

The present investigation extended Boakes' (1969*b*) analysis of the generality of the bisection technique by varying the distribution of a constant number of generalization stimuli within a constant range of stimuli. This manipulation controls for the possible confounding effects of varying the number of generalization stimuli, and also produces larger changes in the stimulus distribution than have been previously used.

METHOD

Subjects

Two male albino rats, obtained from Hill-top Farms, Inc., were maintained at 80% of their free-feeding weights and were 100 to 110 days old at the beginning of the experiment.

Apparatus

The experimental enclosure was a shock-mounted 504.3 cm³ refrigerator shell lined on all interior surfaces with 6.0 cm of Styrofoam board. The floor level was raised with Styrofoam board blocks and a 4.5-cm partition was inserted to divide the area into experimental and equipment sections. The equipment section housed a pellet dispenser (Davis, Model PD 104) and a response-lever mounting (custom built). A slot in the partition accommodated the tube from the pellet dispenser and the lever. The experimental section measured 33.0 by 33.0 by 55.0 cm. The experimental cage was constructed of stainless-steel rods, 1.27 cm apart, mounted horizontally in a narrow Lucite frame. The cage dimensions were 20.3 cm by 14.6 cm by 12.7 cm. Figure 1 is a diagram of the experimental cage, showing the location of the observing-response lever, food magazine, water bottle spout, and the two choice levers (custom built). The observing-response lever required a force of 0.02 N (2.0 g) to cause a microswitch closure and a force of 0.08 N (8.0 g) caused microswitch closures for each of the choice levers. A stainless-steel pan containing a 5.0-cm depth of Ab-Sorb-Dri animal bedding was situated below the cage to collect feces and urine. Centered 8.0 cm above the cage was a shock-mounted Janszen Electro-

Fig. 1. Diagram of the experimental cage, showing the location of the food magazine, water bottle spout, choice-response levers, and observing-response lever.

static speaker (Model 65) and a separately powered 0.17-A light bulb. A sound-silenced ventilating unit (custom built, Industrial Acoustics Co.) provided a complete change of air in the boxes every 3 min through two apertures in the rear of the chamber. These arrangements provided a uniform sound field within the acoustically transparent animal cage. All sound levels to follow are specified in terms of a reference level of 20 $\mu\text{N}/\text{m}^2$ (SPL). When a 4-kHz tone was present at 90 dB, point-to-point differences within the cage did not exceed 2 dB. With the chamber door closed and with no sound input, the background level of midrange frequency noise was about 30 dB. Ambient sound levels were measured with a General Radio Sound Level Meter (Model 1151), set to its A scale. Imposed sound-level measurements were carried out using a Bruel and Kjaer 0.25 in. (0.62 cm) condenser microphone (Type 4136) and a Bruel and Kjaer Microphone Amplifier (Type 2604), set to its root mean square, linear 10 to 200,000 scale.

The sound-generating system was located in the same room as the experimental enclosure. Scheduling and response-recording equipment were situated in an adjacent room. The sound

stimuli were 4-kHz tones of fixed intensity. The tones were generated by a Wavetec Function Generator (Model 111), the output of which was fed to a Scientific Prototype Audio Switch (Model 4042-J). The audio switch permitted the signal to be reduced to zero amplitude or increased to maximum amplitude within 50 msec, thus eliminating switching transients. The audio switch output was fed to a custom built amplifier (Scientific Prototype) before passing to the attenuation panel, where any one of a series of Daven fixed attenuators (Type T-691) could be selected. The output of the attenuation panel was led to a Bruel and Kjaer Band Pass Filter (Type 1612) set to one-third octave around 4 kHz, and from there to the final stage amplifier (custom built, Scientific Prototype), which was connected to the speaker. Sound stimuli and food reinforcement were scheduled by means of relay and timing circuits. Data were recorded on Sodeco Counters.

Procedure

Discrimination training. A self-paced, two-choice discrete trials paradigm was employed in which the animals were trained to discriminate between two intensities (90 and 50 dB) of a 4-kHz tone. In the presence of the 90-dB tone, choice response A (response on lever 1 for Rat 61; lever 2 for Rat 63) terminated the stimulus and produced a food pellet (Noyes, 4 mm, 45 mg). When the 50-dB tone was present, choice response B (response on lever 2 for Rat 61; lever 1 for Rat 63) produced the same events. If an incorrect response was made, the only consequence was termination of the stimulus. Stimulus onset, beginning the trial, was initiated by a response on the observing lever. The stimulus remained on until terminated by a response. The houselight turned off simultaneously with auditory stimulus termination, and remained off until the next trial. Responses occurring in the intertrial interval (1.5 sec) produced no scheduled effects.

During an initial phase of two days, the animals were trained to make the observing and choice responses. Then, the animals received discrimination training with a correction procedure. Under this procedure, incorrect choice responses produced the same stimulus on the next trial, and food pellets were obtained for each correct response.

The percentage of reinforcement for correct

choice responses was gradually reduced from 100% to 25%. A total of 200 reinforcers was scheduled for each session, so that the total number of trials per session varied with the probability of reinforcement. When the correction procedure was not in effect, each stimulus was presented on 50% of the trials in a predetermined, counterbalanced sequence. For Rat 61, only the first eight sessions of 100% reinforcement used a correction procedure; for Rat 63, this procedure was used only in the first 11 such sessions.

Generalization testing. The testing phase utilized a maintained generalization procedure. Several new intensities, intermediate in value to the training stimuli, were now presented on 50% of the trials. Choice responses in the presence of the intermediate test intensities were never reinforced, while 50% of the correct choice responses in the presence of the training stimuli were reinforced. This was done to maintain the overall percentage of reinforcement at 25%, as it was in the final phase of discrimination training.

The generalization stimuli were presented in a predetermined counterbalanced sequence. However, the specific stimuli presented in generalization varied between sessions. The range was always 90 to 50 dB, though nine different combinations of stimuli were employed in order to vary the distribution of stimuli within this range. Table 1 presents the nine sets of generalization stimuli and the sequence in which they were used.

RESULTS

Discrimination Training

The course of training was similar for both animals. In the final stages of training, correct

Table 1
Distribution and order of presentation of generalization stimuli.

Generalization Stimuli (dB)	Session Number	
	Rat 61	Rat 63
50, 55, 60, 65, 90	5, 6, 7,	14, 15, 16
50, 55, 60, 70, 90	13	18
50, 55, 65, 70, 90	17	—
50, 60, 70, 80, 90	8, 9, 10	11, 12, 13
50, 60, 75, 80, 90	1, 4	1, 2, 3, 8, 9, 10
50, 70, 75, 85, 90	15, 16	—
50, 70, 80, 85, 90	14	19, 20
50, 75, 80, 85, 90	2, 3	4, 5, 6, 7
50, 80, 90	11, 12	17

Table 2

Per cent "A" responses, bisection points, and means of generalization stimulus sets for Rat 61.

Mean of Generalization Stimulus Set (dB)	Per Cent "A" Responses									Bisection Point (dB)
	Stimulus Intensity (dB)									
	50	55	60	65	70	75	80	85	90	
64.93	3.00	0.00	0.00	0.00					100.00	77.50
	0.00	0.00	1.69	0.00					98.95	77.63
	0.00	0.98	0.00	1.98					99.39	77.32
65.76	0.00	0.00	0.00		0.00				97.51	80.25
66.59	0.00	0.00		0.78	4.72				91.74	80.41
69.91	0.00		3.22		3.27		59.01		100.00	78.38
	0.00		0.00		1.90		70.19		100.00	77.04
	0.00		0.00		0.00		47.16		100.00	80.54
70.87	0.00		0.76			8.59	41.08		96.66	81.60
	1.11		0.00			6.42	40.00		100.00	81.67
73.24	0.58				0.00	6.73		92.38	91.81	80.05
	0.00				0.00	5.30		84.07	90.86	80.67
74.06	0.00				0.00		29.83	87.90	97.51	81.74
74.90	0.00					3.38	23.07	72.64	97.96	82.72
	0.00					3.73	14.95	68.86	97.68	83.25
75.00	0.72						13.49		98.52	84.29
	0.00						19.56		99.41	83.81

Table 3

Per cent "A" responses, bisection points, and means of generalization stimulus sets for Rat 63.

Mean of Generalization Stimulus Set (dB)	Per Cent "A" Responses									Bisection Point (dB)
	Stimulus Intensity (dB)									
	50	55	60	65	70	75	80	85	90	
64.93	0.57	4.67	6.54	3.77					100.00	77.01
	0.00	0.65	1.97	0.00					100.00	77.50
	0.00	0.00	0.75	0.00					99.06	77.62
65.76	0.00	0.90	1.83		0.00				94.91	80.54
69.91	2.50		1.02		1.02		42.85		98.11	81.29
	0.00		6.42		6.48		41.12		98.86	81.54
	0.00		0.75		4.51		57.89		99.53	78.52
70.87	0.00		0.00			1.53	30.00		99.52	82.89
	0.00		0.00			0.98	18.62		99.39	83.89
	0.92		1.49			3.78	29.32		94.90	83.15
	1.05		0.00			3.44	10.34		100.00	84.42
	0.00		2.89			1.44	23.18		100.00	83.49
	0.00		0.00			0.00	13.58		100.00	84.21
74.06	0.00				0.00		5.88	67.64	89.15	83.57
	0.00				1.33		9.39	73.33	90.94	83.17
74.90	1.50					1.62	4.87	31.70	90.00	86.57
	0.92					0.75	2.27	49.24	89.30	85.09
	0.00					0.81	8.19	56.55	97.98	84.32
	0.00					0.00	1.76	18.42	98.37	86.97
75.00	0.00						18.01		98.95	83.95

choice responses occurred on approximately 98% of the trials. Furthermore, the animals had approximately equal accuracy to each stimulus in the 25% reinforcement condition: for Rat 61, errors occurred on 1.10% of the 90-dB trials and on 0.26% of the 50-dB trials; for Rat 63, errors occurred on 2.8% of the 90-dB trials and on 1.09% of the 50-dB trials.

Generalization Testing

Choice responses made in the presence of the test and training stimuli were converted into a per cent of "A" responses measure (percentage of responses on the correct choice lever for the 90-dB stimulus) for each stimulus. These percentages are presented for each generalization session for Rat 61 and Rat 63 in Tables 2 and 3, respectively. The per cent of "A" responses in the presence of 90 dB was approximately 100%, while for 50 dB it was approximately 0%. Test stimuli usually yielded intermediate values. However, in the case of

the 50-, 55-, 60-, 65-, 90-dB and the 50-, 55-, 60-, 70-, 90-dB distributions, the per cent "A" responses increased abruptly from 0% to approximately 100%.

The bisection point was defined as the stimulus intensity that would be responded to 50% of the time as if it were 90 dB. Tables 2 and 3 also contain the bisection points obtained from the generalization data by linear interpolation and the means of the stimulus distributions (weighted for frequency of presentation of each intensity) presented in generalization. From Tables 2 and 3 it can be seen that, in general, changes in the bisection points reflect behavioral changes in the whole generalization gradient. This is not the case, however, for the 50-, 55-, 60-, 65-, 90-dB and the 50-, 55-, 60-, 70-, 90-dB distributions. Interpolation in these cases produces a bisection point whose value is determined by the last stimulus for which a 0% "A" response was obtained. This is illustrated in Figure 2, which compares the mean 50-, 55-, 60-, 65-, 90-dB gradients of Rats

Fig. 2. Per cent "A" responses as a function of the stimulus intensity for the 50, 55, 60, 65, 90 dB; 50, 60, 70, 80, 90 dB; 50, 60, 75, 80, 90 dB; and 50, 75, 80, 85, 90 dB generalization stimulus distributions for Rat 61 and Rat 63.

61 and 63 with three other gradients for which there is a more gradual change in the per cent of "A" responses. The whole generalization gradient varies with the distribution of generalization stimuli for the 50-, 60-, 70-, 80-, 90-dB, the 50-, 60-, 75-, 80-, 90-dB and the 50-, 75-, 80-, 85-, 90-dB distributions. For instance, the per cent "A" responses that occurred in the presence of the 80-dB stimulus changes markedly across these three distributions, as does the bisection point. It should also be noted that no systematic effects are discernible on responding in the presence of the training stimuli. On the other hand, the 50-, 55-, 60-, 65-, 90-dB gradient is essentially a step function for which the bisection point is indeterminant.

Since it is not possible to obtain a valid bisection point for the 50-, 55-, 60-, 65-, 90-dB and the 50-, 55-, 60-, 70-, 90-dB distributions, these data are not used in further analyses. The remaining distributions are *not* subject to this criticism. Therefore, the bisection points of these distributions are used to represent the behavioral changes caused by manipulating the distribution of generalization stimuli. Since there is no single test intensity common to all distributions, this use of the bisection points allows a quantitative analysis of the data that would otherwise be impossible.

As is apparent from Tables 2 and 3, the bisection points are not constant, but increase as the mean of the distribution of generalization stimuli increases. Pearson product-moment correlation coefficients, computed from the means of the stimulus distributions and the obtained bisection points, indicate that manipulations of the generalization stimulus distribution can account for 46.2% of the variability in the bisection points of Rat 61 and Rat 63 (for Rat 61: $r = 0.68$, $df = 11$, $t = 3.07$, $p < 0.01$; for Rat 63: $r = 0.68$, $df = 14$, $t = 3.50$, $p < 0.005$). Although the generalization tests were not run in any particular order, (*i.e.*, ascending or descending), it is possible that the changes observed in the over-all gradients and in the bisection points were due to the steepening of the gradients with time. To assess this factor, Pearson product-moment correlation coefficients for the session number and the obtained bisection points were computed. For Rat 61, it was found that $r = -0.19$ ($df = 11$, $t = 0.66$, $p > 0.05$), and for Rat 63 it was found that $r = -0.32$ ($df = 14$, $t = 1.27$, $p > 0.05$).

DISCUSSION

The present data indicate that the bisection point, defined as that stimulus intensity that would be responded to 50% of the time as if it were 90 dB, is strongly influenced by changes in the distribution of generalization stimuli within a constant range. This factor accounted for 46% of the variability observed in the bisection points. The alternative explanation, that the bisection points changed because of the steepening of the gradients with time, is, of course, obviously inadequate. The correlations for both animals between the sequence of the generalization tests and the obtained bisection points were not significantly different from zero.

Boakes (1969*b*) also investigated the effects of varying the distribution of generalization stimuli upon bisection points obtained with a similar procedure. He produced changes in the distribution of generalization stimuli by varying the number of stimuli presented. He obtained a higher bisection point when the stimulus distribution had a higher mean, although this increase was not statistically significant. In the present study, large and statistically significant changes in the bisection point were demonstrated. The disparity in results may lie in the range of differences in the means of the stimulus distributions employed. Boakes utilized a range of only 0.07 log units in the mean of the stimulus distribution, whereas that of the present study varied by more than a full log unit.

A technique for obtaining bisection data from animals would seem to be of potential value because such data could be used for psychophysical scaling in a manner analogous to that employed with humans (Boakes, 1969*b*; Fagot, 1963; Stevens, 1955). However, the demonstration that the bisection point is subject to variations that are not primarily due to changes in the interval bisected is a strong argument against the use of bisection data for the purpose of scaling. Similar arguments have been raised against the use of bisection data in human psychophysics because the scale derived from such data appears to be uniquely dependent upon the specific interval bisected (Stewart, Fagot, and Eskildsen, 1967). In the present instance, the derived scale would be uniquely dependent upon the particular test stimuli employed.

REFERENCES

- Boakes, R. A. Response continuity and timing behavior. In R. M. Gilbert and N. S. Sutherland (Eds.), *Animal discrimination learning*. London: Academic Press, 1969. Pp. 351-389. (a)
- Boakes, R. A. The bisection of a brightness interval by pigeons. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 201-209. (b)
- Fagot, R. F. On the psychophysical law and estimation procedures in psychophysical scaling. *Psychometrika*, 1963, 28, 145-160.
- Helson, H. *Adaptation level theory*. New York: Harper & Row, 1964.
- Stevens, S. S. The measurement of loudness. *Journal of the Acoustical Society of America*, 1955, 27, 815-829.
- Steward, M. R., Fagot, R. F., and Eskildsen, P. R. Invariance tests for bisection and fractionation scaling. *Perception and Psychophysics*, 1967, 2, 323-327.

Received 15 May 1974.

(Final Acceptance 9 January 1975.)