BIAS FUNCTIONS AND OPERATING CHARACTERISTICS OF RATS DISCRIMINATING AUDITORY STIMULI

ANN L. HUME AND R. J. IRWIN[1]

UNIVERSITY OF AUCKLAND, NEW ZEALAND

Rats were trained to discriminate between two bursts of random noise that differed in intensity. In a two-lever, discrete-trial procedure, correct responses were reinforced with brain stimulation, and incorrect responses produced timeout. Responding was studied as a function of the decibel difference between the stimuli, the probabilities of presenting the stimuli, the relative duration of timeout consequent upon the two types of incorrect responses, and the absolute duration of timeout consequent upon incorrect responses. The results showed that the distribution of responses between the two levers depended upon the stimulus probabilities, but were independent of either the absolute or relative durations of timeout. When the stimulus probabilities were varied, the response probabilities did not match the stimulus probabilities; when the relative durations of timeout were varied, the animals did not obtain the maximum rate of reinforcement per unit time. Instead, the animals distributed their responses so as to obtain the maximum number of reinforcements at each level of discrimination. In addition, the level of discrimination increased as a function of the decibel difference between the stimuli.

Contemporary psychophysical theory (Green and Swets, 1966) distinguishes between variables that determine an organism's sensitivity or ability to discriminate stimuli, and variables that determine how an organism responds in the presence of discriminable stimuli. Many studies with humans have shown that while a subject may be induced to change his response probabilities in the presence of either of two stimuli, that is, his response bias or his tendency to prefer one response over another, his ability to discriminate between them remains constant. Tanner and Swets (1954), Swets, Tanner, and Birdsall (1961), Markowitz and Swets (1967), and Schulman and Greenberg (1970), for example, have demonstrated that response bias can be systematically controlled by varying the probability of presenting one of two stimuli; Tanner and Swets (1954), Swets et al. (1961), Green and Swets (1966), and

Galanter and Holman (1967) have also demonstrated that response bias can be controlled by varying either the scores or the monetary consequences of responses in the presence of the different stimuli. These studies together show that in auditory and visual psychophysical experiments human subjects perform in a manner that results in almost maximum outcome.

Psychophysical studies with animals, in which response bias has been studied as a function of either stimulus probabilities or response consequences, are fewer. Hack (1963) investigated the effects of varying stimulus probabilities in a psychophysical procedure with rats. The data were unsystematic, possibly because they were based on too few trials. Irwin and Terman (1970) noted the occurrence of response bias in an auditory discrimination task with rats, but they did not attempt to control it. Recently, Clopton (1972) and Terman and Terman (1972) reported systematic changes in response bias with animals as a function of varying stimulus magnitudes and stimulus probabilities. Stubbs (1968) also demonstrated that the response bias of pigeons discriminating stimulus duration in a two-key procedure can be changed by varying the contingencies of reinforcement. In each of these studies, response bias was shown to

be independent of stimulus discriminability. In three of the present experiments, response bias was studied as a function of varying either the stimulus probabilities or the consequences of one response relative to the consequences of the other response. In a fourth experiment, both response bias and accuracy of discrimination were studied under variations in the overall outcomes of responses.

METHOD

Subjects

Nine male albino rats, designated A-IV, A-VI, A-VII, A-IX, A-X, A-XII, A-XIII, A-XIV, and A-XVI, were all naive at the beginning of these experiments. Two animals, A-VII and A-IX, served successively in Experiments I, II, and III described below. The animals were given unlimited access to food and water in their homecages.

Apparatus

The experimental chamber consisted of transparent Perspex side walls and ceiling, aluminum front and rear walls, and a grid floor. Its internal dimensions were 30 cm long, 25 cm wide, and 26 cm high. Two stainless steel levers, requiring a force of 0.15 N to depress them, protruded 1.8 cm through the front wall, 16.5 cm from the floor, and 4 cm from each side wall. A set of lights above each of these levers was illuminated when a trial was in progress. A third lever, requiring a force of 0.14 N to depress it, was located centrally, 4.5 cm above the floor. A speaker was also mounted centrally, 19 cm above the floor.

The compartment was placed inside a ventilated, sound-attenuating chamber containing a houselight. Brain stimulation from a constant-current source was delivered through a commutator mounted in the ceiling of the chamber. Each brain stimulation consisted of a 50-Hz alternating current, adjusted in level for each animal, and monitored by an ammeter and an oscilloscope.

The auditory stimuli consisted of 0.5-sec bursts of random noise of undetermined bandwidth. The noise was produced by a Zener diode and then amplified. On any trial, one of two stimuli differing only in intensity was presented. The intensity of one stimulus, S_1, was held constant throughout the experiment at 69 decibels (dB) as measured on the A-

weighting network of a Dawe sound-level meter (Type 1400 G) placed inside the open chamber approximately 5 cm above the center response lever. The intensity of a seond stimulus, S_2, was varied up to 20 dB above S_1 by means of a variable attenuator (Hewlett Packard, Type 350C). The voltage across the speaker was monitored with a quasi-RMS voltmeter (Brüel and Kjaer, Type 2410).

The probability of presenting each stimulus was controlled by a specially constructed "probability generator", which contained a multivibrator, free-running at 10,000 Hz. If the animal pressed the center lever when the multivibrator was in one state, S_1 was presented, and if the multivibrator was in its other state, S_2 was presented. By varying the relative time the multivibrator was in one state or the other, the probability of presenting one of the stimuli could be varied between 0.1 and 0.9 in steps of 0.1.

Procedure

Electrode implantation and histology. The animals were implanted bilaterally, under sodium pentobarbital (Nembutal) anaesthesia, with acrylic-insulated, stainless steel, monopolar electrodes, aimed at the medial forebrain bundle. The loci of the tips in terms of the Kreig stereotaxic coordinates, were 0.8 mm posterior and 1.7 mm lateral to bregma, and 8.2 mm ventral to the top of the skull. An indifferent electrode was provided by a stainless-steel wire loop placed over the top of the skull. The electrodes were attached to the top of the skull with dental cement and stainless steel screws. After the experiments, the animals were sacrificed and perfused with saline and

■ A-IV   ▲ A-X
○ A-VI   + A-XII
▲ A-VII × A-XIII
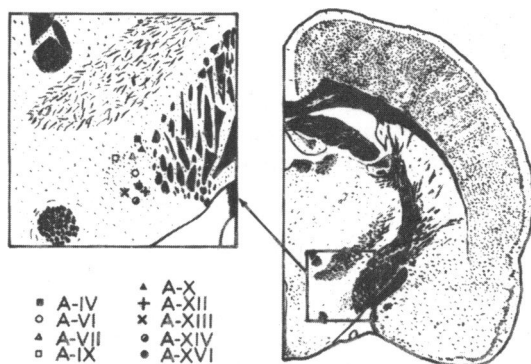□ A-IX   ● A-XIV
         ● A-XVI

Fig. 1. Placement of the stimulating electrode tip for each animal. All animals were stimulated on the right side of the brain.

neutral-buffered formalin solutions. The brains were washed in water, quenched in freon and held in liquid nitrogen before sectioning in a cryostat microtome. Sections were placed in a photographic enlarger and prints made (Thompson, 1971). All electrode tips were found to be in the lateral hypothalamus. Figure 1 shows the placement of the stimulating electrode tip for each animal. All animals were stimulated in the right side of the brain.

Preliminary training. The animals were trained to press the center lever of the compartment to begin a trial. One response on the center lever turned on the lights over the two side levers and either of two intensities of noise was presented for 0.5 sec with a probability of 0.5. The intensities were held constant during preliminary training, S_1 at 69 dBA, and S_2 at 89 dBA. A single response on the left-hand lever, R_1, after presentation of S_1, or on the right-hand lever, R_2, after presentation of S_2, produced a 0.5-sec burst of brain stimulation. The current levels were adjusted for each animal so as to maintain rapid responding. The RMS values of the current were $40\mu A$ for A-XIII, $50\mu A$ for A-XIV, $65\mu A$ for A-IV, and $70\mu A$ for A-VI, A-VII, A-IX, A-X, A-XII, and A-XVI. Incorrect responses after presentation of either stimulus produced a 5-sec timeout. During timeout, all lights were extinguished and responses had no scheduled consequences. The duration of a trial was set at 5 sec, so that if an animal did not respond on either side lever within 5 sec of pressing the center lever another press on the center lever was necessary to start a new trial. This occurred approximately once in 5000 trials on the average. Daily sessions of 1000 trials, lasting approximately 50 min, were given during preliminary training. The duration of a session varied from 40 to 100 min in the following experiments.

EXPERIMENT I

Four animals served in this experiment, A-IV, A-VI, A-VII, and A-IX. Initially, the intensity difference between the stimuli was 20 dB (S_1 was 69 dBA and S_2 was 89 dBA). The probability of S_2 occurring on any trial, $p(S_2)$, was 0.5. When responding to the two side levers was judged to be stable, the decibel difference between S_1 and S_2 was decreased and then increased again in discrete steps as follows: 20, 15, 10, 8, 5, 8, 10, 15, and 20 dB. For the first series of stimulus differences, $p(S_2)$ was 0.5 for all animals. The same series of stimulus differences was then presented twice at each of four different values of $p(S_2)$. Two animals, A-IV and A-VI, were exposed to values of $p(S_2)$ in the following order: 0.5, 0.7, 0.8, 0.8, 0.7, 0.5, 0.3, 0.2, 0.2, and 0.3. The other two animals, A-VII and A-IX, were exposed to values of $p(S_2)$ for each series of stimulus differences in the reverse order: 0.5, 0.3, 0.2, 0.2, 0.3, 0.5, 0.7, 0.8, 0.8, and 0.7.

As in the preliminary training, correct responses produced 0.5-sec bursts of brain stimulation, and incorrect responses produced 5-sec periods of timeout. Animals were studied for one daily session at a given stimulus difference and a given value of $p(S_2)$ within each series of stimulus differences and series of values of $p(S_2)$. Each daily session consisted of 1000 trials, preceded by 200 warmup trials. Data were recorded in blocks of 500 trials.

The same animals were then exposed to a series of decreasing stimulus differences: 20, 15, 10, 8, 5, 3, and 0 dB. One animal, A-IV, was also exposed to a difference of 2 dB. For this series of stimulus differences, $p(S_2)$ was 0.5, and animals were exposed to each difference for five daily sessions.

EXPERIMENT II

Throughout this experiment, two animals, A-VI and A-IX, were exposed to a constant stimulus difference of 5 dB, and two, A-IV and A-VII, to a difference of 3 dB. Initially, $p(S_2)$ was 0.5; it was then increased or decreased in steps of 0.1. The order of $p(S_2)$ for A-IV and A-VI was: 0.5, 0.6, 0.7, 0.8, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.2, 0.3, 0.4, and 0.5. The order of $p(S_2)$ was reversed for A-VII and A-IX.

Correct and incorrect responses produced the same consequences as in Experiment I. Five daily sessions (1000 test trials and 200 warmup trials) occurred at each successive value of $p(S_2)$ within the series.

EXPERIMENT III

Two animals, A-VII and A-IX, were exposed to a constant stimulus difference of 5 dB throughout this experiment. The probability,

$p(S_2)$, was held constant at 0.5, and correct responses always produced 0.5-sec bursts of brain stimulation. Initially, incorrect responses to either lever produced 5-sec periods of time-out. The relative duration of timeout produced by incorrect responses on either lever was then changed. For A-VII, the timeout consequence upon responding on the right-hand lever, R_2, after the presentation of S_1 was systematically increased relative to the timeout consequent upon responding on the left-hand lever, R_1, after the presentation of S_2. The equal periods of timeout were then reinstated before the consequences were reversed. The sequence of the relative durations of timeout (seconds) for the incorrect responses (R_2/S_1): (R_1/S_2) for A-VII were 5:5, 7.5:5, 10:5, 15:5, 20:5, 30:5, 30:3, 30:2, 30:1, 5:5, 5:10, 5:20, 3:30, and 1:30. A-IX was exposed to an opposite, but similar sequence of relative timeouts. Each relative duration of timeout was presented for five sessions.
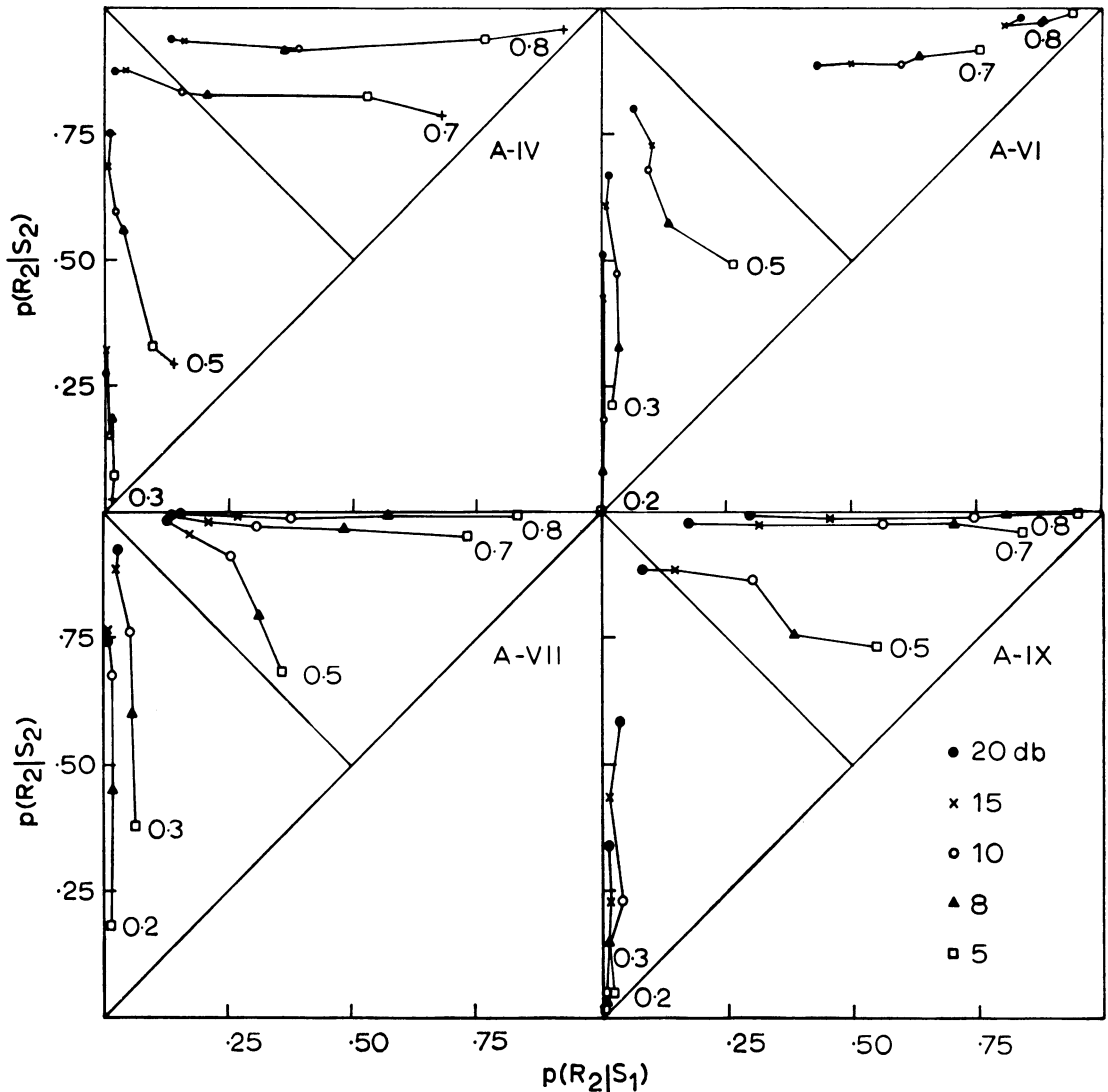

Fig. 2. Bias functions. The probability of a response on the right-hand lever after the presentation of S_2, $p(R_2/S_2)$, as a function of the probability of a response on the right-hand lever after the presentation of S_1, $p(R_2/S_1)$. Each point, based on 4000 trials, was obtained at a different stimulus difference (dB) and a different probability of presenting S_2, $p(S_2)$. The intensity of S_1 was 69 dBA, and S_2 was varied from 5 to 20 dB above S_1. The lines join points obtained at the different values of $p(S_2)$ indicated.

EXPERIMENT IV

Five animals, A-X, A-XII, A-XIII, A-XIV, and A-XVI, served in this experiment. On three different occasions they were exposed to a series of decreasing stimulus differences: 20, 15, 12, 10, 8, 5, 3, and 0 dB. One animal, A-XVI, was also exposed to differences of 2 and 1 dB later in the experiment. Throughout the experiment $p(S_2)$ was 0.5, and correct responses produced 0.5-sec bursts of brain stimulation.

On the first occasion of exposure to the series of stimulus differences, incorrect responses produced 5-sec periods of timeout. On the second and third exposures, the periods of timeout were either increased or decreased for each animal, but remained equal for both types of incorrect responses. The orders of timeout were: 5, 7.5, and 10 sec for A-X; 5, 3, and 1 sec for A-XII and A-XVI; 5, 7.5, and 3 sec for A-XIII; and 5, 7.5, and 1 sec for A-XIV. There were three sessions at each stimulus difference within each series of timeouts.

RESULTS

Experiment I

Figure 2 shows the probability of a response on the right-hand lever (R_2) after the presentation of S_2, $p(R_2/S_2)$, as a function of the probability of a response on the right-hand lever after the presentation of S_1, $p(R_2/S_1)$, for each of five stimulus differences. Each point is the average of the response probabilities derived from four separate sessions: in two sessions the intensity of S_2 was decreased between sessions, and in two the intensity of S_2 was increased between sessions. Each point is therefore based on 4000 trials.

The lines join points obtained at each of five different values of $p(S_2)$, and hence represent bias functions: they show how an animal's response bias to the right-hand lever, $p(R_2)$, varied as a function of the intensity difference at each $p(S_2)$. In the absence of bias, points would lie along the minor diagonal running between the top-left corner and the center of the figure. A bias to the right-hand lever is represented by points lying above the minor diagonal, and a bias to the left-hand lever by points lying below that diagonal. When $p(S_2)$ was 0.7 and 0.8, the rats displayed a marked bias to the right-hand lever, and when $p(S_2)$

was 0.2 and 0.3 they displayed a marked bias to the left-hand lever. When $p(S_2)$ was 0.5, two animals, A-IV and A-VI exhibited biases to the left-hand lever, and two, A-VII and A-IX, exhibited biases to the right-hand lever.

Figure 2 also shows that the response probabilities varied as a function of the intensity difference between S_1 and S_2. Points in the upper-left corner, where $p(R_2/S_2)$ is high and $p(R_2/S_1)$ is low, resulted from large intensity differences; points near the major diagonal, where $p(R_2/S_2)$ and $p(R_2/S_1)$ are more nearly equal, resulted from small intensity differences. The former points represent high accuracy of discrimination, and the latter points represent low accuracy of discrimination.

Figure 3 shows the results of the second part of Experiment I when the animals were exposed to each intensity difference in decreasing order for five sessions. The figure shows the percentage of correct responses as a function of the decibel difference between S_1 and S_2. Each point is based upon the last 2500 trials recorded at each intensity difference. The line connects the mean percentage of correct responses for the group at each decibel differ-
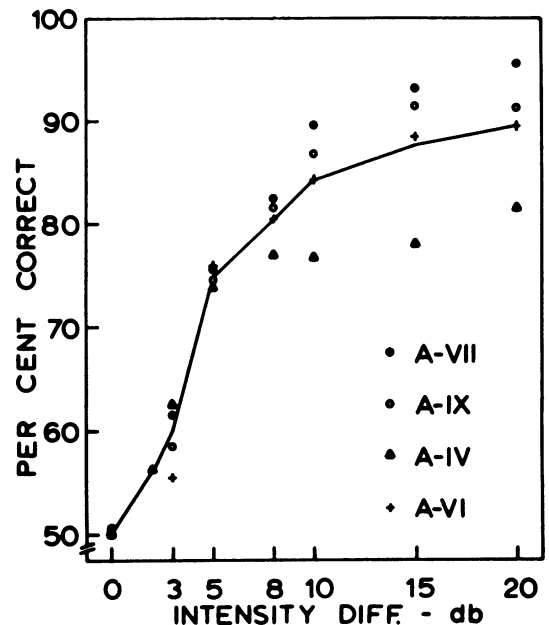

Fig. 3. Percentage of correct responses as a function of the decibel difference between S_1 and S_2. The intensity of S_1 was 69 dBA, and the intensity of S_2 was decreased from 20 to 0 dB above S_1 in discrete steps. The probability of presenting S_2, $p(S_2)$ was 0.5. Each point is based upon 2500 trials. The line connects the mean percentage of correct responses for the four subjects at each decibel difference.

ence. This psychometric function shows that the percentage of correct responses increased monotonically from chance level of 50% at a zero stimulus difference to about 90% at large stimulus differences. A difference of 5 dB between the stimuli maintained about 75% correct responses for each animal.

Experiment II

Figure 4 shows $p(R_2/S_2)$ as a function of $p(R_2/S_1)$ for a range of values of $p(S_2)$ (0.1 to 0.9) at a constant stimulus difference. For A-VI and A-IX the difference between S_1 (69 dBA) and S_2 was 5 dB, and for A-IV and A-VII the difference was 3 dB. Each point is based on 4000 trials: 2000 when $p(S_2)$ was presented in an ascending order and 2000 when $p(S_2)$ was presented in a descending order. Points obtained at a value of $p(S_2)$ of 0.5 are based on 6000 trials, and points obtained at values of $p(S_2)$ of 0.1 and 0.9 are based on 2000 trials. Animals were not exposed to these latter prob-
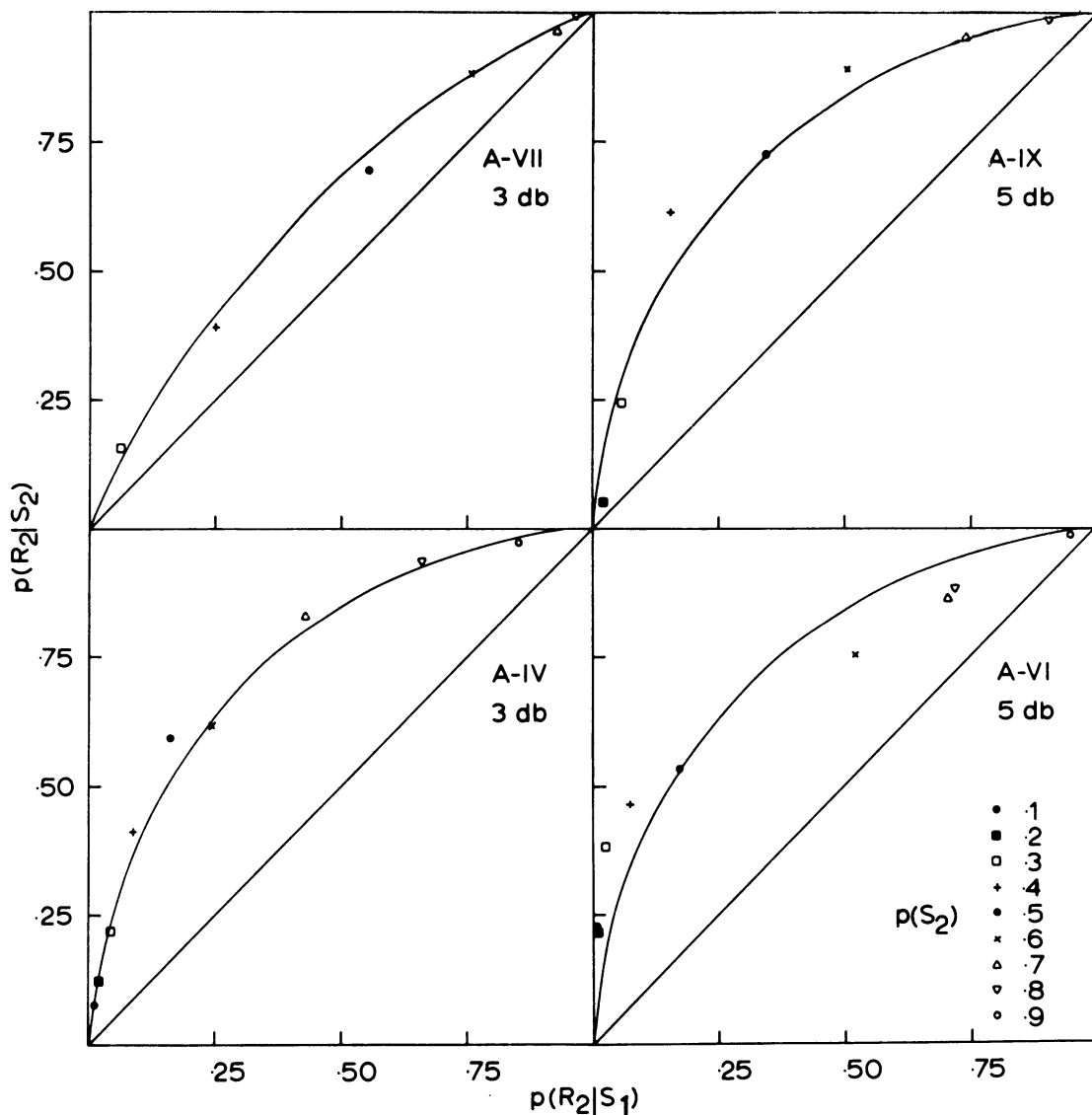

Fig. 4. ROC curves. The probability of a response on the right-hand lever after the presentation of S_2, $p(R_2/S_2)$, as a function of the probability of a response on the right-hand lever after the presentation of S_1, $p(R_2/S_1)$, at each value of $p(S_2)$. The difference between S_1 (69 dBA) and S_2 was 3 dB for A-VII and A-IV, and 5 dB for A-IX and A-VI. Each point is based on 4000 trials, except points obtained when $p(S_2)$ was 0.5 (6000 trials), and when $p(S_2)$ was 0.1 and 0.9 (2000 trials). The curves were visually fitted to each set of points.

abilities if they exhibited almost exclusive response biases to one or other lever at less extreme probabilities.

The series of points for increasing values of $p(S_2)$ for each subject show that $p(R_2/S_2)$ is a monotonically increasing, negatively accelerated function of $p(R_2/S_1)$, as described by the curve that has been visually fitted to each set of data. These curves show how $p(R_2/S_2)$ and $p(R_2/S_1)$ covary, for a constant level of discriminability, according to the theory of signal detection (Green and Swets, 1966). The parameter of each, d', represents an index of stimulus discriminability. For curves of this form, d' ranges from 0.00, when it falls along the major diagonal of the figure representing no discrimination, to ∞, when it follows the left and upper coordinates of the figure, representing perfect discrimination. The values of d' are 1.04 for A-IV, 0.44 for A-VII, and 1.00 for A-VI and A-IX. The data points in Figure 4 show that the animals' response biases varied widely as a function of $p(S_2)$, but the close fit of the curves to each set of points indicates that the animals' ability to discriminate the fixed difference between S_1 and S_2 remained constant and independent of response bias. The values of d' for each animal show that A-VI and A-IX exhibited identical levels of discrimination for a stimulus difference of 5 dB, but that A-IV and A-VII exhibited rather different levels of discrimination for a stimulus difference of 3 dB.

Experiment III

When the relative durations of timeout for the incorrect responses $(R_2/S_1:R_1/S_2)$ were changed from 5:5 sec to either 1:30 or 30:1 sec, changes in the response probabilities to either lever were either very small or negligible. When the timeout for an incorrect response on the right-hand lever (R_2/S_1) relative to the timeout for an incorrect response on the left-hand lever (R_1/S_2) was increased from a ratio of 5:5 sec to a ratio of 30:1 sec, A-VII showed a decrease in $p(R_2)$ of 0.094 (from 0.643 to 0.549), and A-IX showed a decrease in $p(R_2)$ of 0.137 (from 0.572 to 0.435). For the reverse changes in the timeout durations, A-VII showed an increase in $p(R_2)$ of 0.121, and A-IX, an increase of 0.237. None of these changes in response bias was large relative to the 30-fold changes in the relative durations of timeout.

Experiment IV

Figure 5 shows the percentage of correct responses as a function of the decibel difference between S_1 and S_2 for five subjects. Each curve for each subject was obtained under a different duration of timeout for incorrect responses; the duration was the same for each type of incorrect response. Each point is based upon the last 2000 trials of the 3000 trials of exposure to each intensity difference and duration of timeout.

These psychometric functions describe similar relationships between the percentage of correct responses and the decibel difference between the stimuli to that shown in Figure 3. Comparison of the functions for each subject shows that neither their form nor the level of accuracy represented by each point changed systematically with increases or decreases in the duration of timeout. Rather, where differences in the psychometric functions of an animal are readily observable, they can be more plausibly attributed to the order in which the functions were obtained. Thus, A-XVI exhibited greater levels of per cent correct responses under a timeout of 1-sec duration—the last function generated.

Bias functions plotted for each animal of this experiment in the same way as those for the four animals in Figure 3 showed that response bias to one or the other lever was independent of the absolute duration of timeout consequent upon incorrect responses. These functions are not shown, but in no case did response bias either increase or decrease as a function of the periods of timeout.

DISCUSSION

In all experiments, discriminability of the stimuli was a function of the intensity difference between S_1 and S_2. In Experiments I and IV, the discriminability of the stimuli was described by an ogival relationship between the percentage of correct responses and the decibel difference between the stimuli (Figures 3 and 5). Further, in Experiment IV, when the duration of timeout consequent upon both types of incorrect response was varied between 1 and 10 sec, the percentage of correct responses remained virtually unchanged.

Stimulus discriminability was also independent of changes in response bias produced by
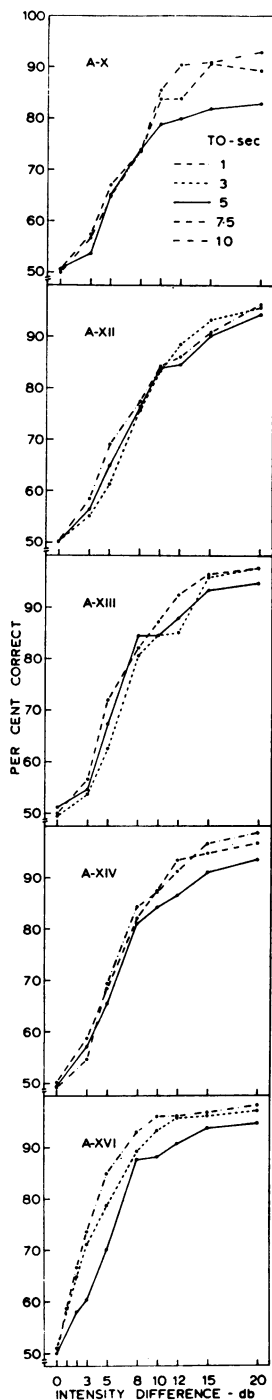
Fig. 5. Percentage of correct responses as a function of the decibel difference between S_1 and S_2. The parameter of each function is the duration of timeout (TO) consequent upon both types of incorrect response. Each point is based upon 2000 trials. A-XVI was the only subject exposed to stimulus-differences of 2 dB with 3- and 1-sec periods of timeout, and of 1 dB with a 1-sec period of timeout.

varying either the stimulus probabilities or the relative durations of timeout consequent upon the two types of incorrect responses. In Experiment II, the set of points representing widely different response biases at a fixed stimulus difference were described by a single constant index of discriminability, d'. In Experiment III, response biases did not vary widely at a fixed stimulus difference with changes in the relative durations of timeout, so that ROC curves describing stimulus discriminability could not be fitted to the points. Discriminability in this case, as in Experiments I and IV, may be indexed by percentage of correct responses. When the relative durations of timeout for incorrect responses were either increased or decreased 30-fold, the small changes in response bias were accompanied by an average decrease in per cent correct responses for the two animals of 2% (from an average of 77%).

Response biases in Experiments I and II changed unequivocally with variation in the stimulus probabilities. In contrast, response biases in Experiment III changed very little with wide variations in the relative durations of timeout for incorrect responses. Figure 6 represents a quantitative comparison of the animal's response biases and the response biases that would result if a subject had obtained the optimal number of reinforcements under each value of $p(S_2)$. This analysis is based on the data obtained when the stimulus difference was constant and $p(S_2)$ was varied from 0.1 to 0.9 (Figure 4). A subject's response bias may be represented by the index of response criterion, β_{obt} proposed by detection theory (Green and Swets, 1966). This index represents the slope of the theoretical detection curves that would pass through each of the points in Figure 4; this index is independent of the level of discrimination represented by each point. Response biases that would result in the optimal number of reinforcements being obtained under each value of $p(S_2)$ may be described by the index β_{opt}. This index represents the ratio of the probability of S_1 occurring to the probability of S_2 occurring on any trial, $p(S_1)/p(S_2)$, when the outcomes for both types of correct response are the same, and the outcomes for both types of incorrect response are the same; it is also, therefore, independent of levels of discrimination.
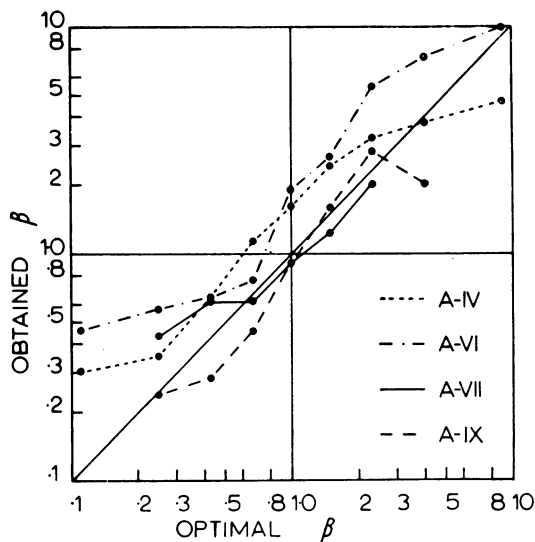
Fig. 6. Relationship between obtained response criteria (β_{obt}) for the data presented in Figure 4, and the optimal response criteria (β_{opt}) defined by statistical decision theory. The coordinates are logarithmically spaced and the major diagonal represents perfect correspondence between obtained and optimal criteria.

Figure 6 shows the relationship between β_{obt} and β_{opt} on logarithmically spaced co-ordinates. The major diagonal represents perfect correspondence between the two variables. The central horizontal axis, for which $\beta_{obt} = 1.0$, corresponds to points lying on the minor diagonal of the ROC space, and hence to no response bias. Points lying above the central axis represent a bias to the left-hand lever, and points below, a bias to the right-hand lever. Points lying between the major diagonal and the central axis in either the upper-right or lower-left quadrants of the figure represent less extreme than optimal biases to the corresponding levers. Similarly, points lying above the major diagonal in the upper-right quadrant, and below the major diagonal in the lower-left quadrant, represent more extreme than optimal biases to the corresponding levers. In Figure 6, the rank order coefficient of correlation between β_{obt} and β_{opt} is unity for each subject except A-IX. Departures of the obtained points from the major diagonal are small, and the close correspondence between the obtained and optimal values of β indicates that the response biases of individual animals resulted in the maximum number of reinforcements under each value of $p(S_2)$. If the response probabilities to the two levers

had matched the stimulus probabilities, the obtained values of β would have fallen between the major diagonal and the central horizontal axis of the figure.

The effects of changes in the relative duration of timeout for incorrect responses may be analyzed in a similar way. Figure 7 compares the relationship between the animals' response biases and the response biases that would have minimized the time spent in timeout. In Experiment III, $p(S_2)$ was 0.5, so that the response criterion, β_{opt}, that would minimize the time spent in timeout, is equal to the ratio of the timeout for an incorrect R_2 response to the timeout for an incorrect R_1 response. Such a criterion, like that calculated for varying $p(S_2)$, is optimal in the sense defined by statistical decision theory (Wald, 1950), because it minimizes overall response costs under each set of experimental contingencies. Such an analysis enables comparison of the animals' response biases with optimal biases so defined. It also provides a framework within which to compare the effects on response bias of varying stimulus probabilities and the relative durations of timeout for incorrect responses.

In Figure 7, the obtained values of β were estimated in the same way as those in Figure 6.
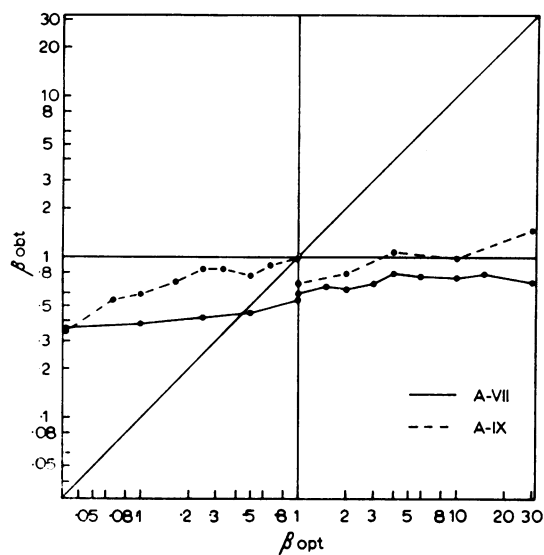

Fig. 7. Relationship between obtained response criteria (β_{obt}) for the results obtained when the relative durations of timeout were varied, and the optimal response criteria (β_{opt}) defined by statistical decision theory. The coordinates are logarithmically spaced and the major diagonal represents perfect correspondence between obtained and optimal criteria.

The coordinates are again logarithmically spaced and the major diagonal represents perfect correspondence between β_{obt} and β_{opt}. When the timeout for incorrect responses is equal, β_{opt} is 1.0. The obtained values of β approximate this value for almost the entire series of β_{opt} values. When $\beta_{opt} = 30.0$, the average β_{obt} value for the two subjects is 1.09. In terms of this analysis, therefore, a ratio of 30:1 in the durations of timeout had the same effect on the animals' response probabilities as a ratio of 1:1 would have on the response probabilities of a subject that was optimizing response outcomes. The 900-fold change in β_{opt} (from 0.033 to 30.0) represented in Figure 7 was correlated with an average three-fold change in β_{opt} for the two subjects (from 0.35 to 1.09). This result means that the subjects' response probabilities were not controlled by the absolute ratios of the periods of timeout, and that the subjects did not minimize the overall cost of incorrect responses, namely the time spent in timeout. The fact that the values of β_{obt} do not depart largely from 1.0, means instead that the subjects optimized the number of reinforcements obtained, irrespective of the overall cost of incorrect responses. Extreme response biases would have resulted in fewer reinforcements being obtained, but less time being spent in timeout.

Further, if the subjects in Experiment III had minimized the time spent in timeout they would also have obtained the maximum number of reinforcements per unit time. These results may be related to those of Experiment IV in which the percentages of correct responses did not vary systematically with changes between 1 and 10 sec in the absolute duration of timeout for the incorrect responses: the subjects maximized the number of reinforcements irrespective of the absolute duration of timeout consequent upon incorrect responses. If they had maximized the number of reinforcements per unit time, it might be predicted that very short periods of timeout would have resulted in a loss of stimulus control, or a decrease in the proportion of correct responses, particularly with small stimulus differences. Also, an increase in response bias as the intensity difference was reduced could have resulted with animals showing an initial response bias, since a high rate of reinforcement could then have been obtained on the preferred lever. The independence of response biases and discrimination accuracy from both the relative and absolute durations of timeout is also surprising in relation to demonstrations of the punishing effects of timeout on behavior in situations in which there are available alternative behaviors to that punished (Azrin and Holz, 1966; Holz, Azrin, and Ayllon, 1963; Holz, Azrin, and Ulrich, 1963). In matching-to-sample tasks, for example, Ferster and Appel (1961) and Zimmerman and Ferster (1963) demonstrated with pigeons that increases in either the duration or the frequency of presentation of timeout consequent upon incorrect responses resulted in decreases in the numbers of those responses. Zimmerman and Bayden (1963) replicated these findings with humans in matching-to-sample tasks. In a psychophysical task with pigeons, Stubbs (1968) found that accuracy of discrimination was greater under variable-ratio than under fixed-ratio schedules of reinforcement, and that accuracy increased with progress through individual fixed ratios. He did not manipulate the duration of timeout consequent upon incorrect responses. In psychophysical research with humans, in contrast, it has been widely demonstrated that asymptotic accuracy of discrimination, once established, is unaffected by changes in response consequences or by offers of bonuses, usually monetary, for further improvements in performance (Blackwell, 1953; Lukaszewski and Elliott, 1962; Green and Swets, 1966, App. III; Galanter and Holman, 1967). In the present experiments, once discrimination was established, both accuracy and response bias were independent of changes in either the relative or the absolute outcomes for incorrect responses.

The relationships in Figures 6 and 7 show that the animals optimized the number of reinforcements when either the stimulus probabilities or the relative durations of timeout were varied. When the stimulus probabilities were varied they did not match their response probabilities to the stimulus probabilities. When the relative durations of timeout were varied, they did not optimize the rate of reinforcement per unit time for responses on either one or both levers. With varying stimulus probabilities, Clopton (1972) obtained similar effects with monkeys, and Terman and Terman (1972) with rats, although they did not present their results in the same way as those presented here.

Finally, these results may be compared with similar results obtained with humans in yes-no psychophysical procedures. When stimulus probabilities are varied, humans tend to match their response probabilities to the stimulus probabilities (Green and Swets, 1966, p. 90; Thomas and Legge, 1970), while when response values and costs are varied they fairly closely optimize overall response outcomes (Green and Swets, 1966; Galanter and Holman, 1967). In the present experiments, the animals' response biases bore a reverse relationship with the stimulus probabilities and the response outcomes.

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