DURATION DISCRIMINATION: EFFECTS OF PROBABILITY OF STIMULUS PRESENTATION

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Monkeys initiated a stimulus by pressing on the center of three levers and the stimulus terminated independently of behavior 60, 80, 90, or 100 sec later. Presses on the right lever were reinforced with food following the three briefer durations, and presses on the left lever, following the 100-sec duration. Incorrect responses produced a 10-sec timeout. Probability of presenting the 100-sec duration was manipulated in the range from 0.25 to 0.75, with the probabilities of the briefer durations remaining equal and summing to one minus the probability of the 100-sec duration. Percentage of responses on either side lever was functionally related to both the probability of presenting the 100-sec stimulus and to stimulus duration. An analysis of the data based on the theory of signal detection resulted in operating characteristics that were linear when plotted on normal-normal coordinates. The percentage of responses on either lever approximated the optimal values for maximizing reinforcement probability in each condition of the experiment.

The theory of signal detection (Green and Swets, 1966) divides variables affecting discrimination performance into two categories, those affecting the discriminability of the stimulus (the physical characteristics of the stimulus itself and the background level of noise, both neural and environmental) and those variables presumed to affect only the observer's criterion for reporting a stimulus, or his response bias (such things as the relative payoff for different response alternatives and the *a priori* probability of presentation of the various possible stimuli). Some of the data analysis procedures implied by the model have proven useful in describing human behavior in a variety of discrimination situations (*e.g.*, Green and Swets, 1966; Swets, 1964), and the possibility of categorizing variables as either affecting discriminability of a stimulus or response bias is attractive, while no doubt oversimplified.

Nevin (1964, 1969, 1970) suggested that the signal-detection model might fruitfully be applied to animal studies of stimulus control, providing a bridge between human and animal psychophysics. To date, a number of investigators have shown that the model adequately describes the data of some animal

experiments dealing with visual (Blough, 1967; Boneau and Cole, 1967; Nevin, 1964) and auditory events (Hack, 1963; Irwin and Terman, 1970; Terman, 1970) and even the dimension of fixed-ratio length (Rilling and McDiarmid, 1965). These experiments all demonstrate that a measure of discriminability, d' , or some derivative thereof varies directly with the strength of a signal, relative to a background of noise. Only a few studies have been concerned with directly manipulating the variables presumed to affect only the observer's criterion or response bias. For example, Nevin (1964) showed that variations in the probability of reinforcement of correct detections of a visual stimulus by a rat resulted in the generation of Receiver Operating Characteristic, or ROC, curves, similar to those demonstrated for human observers in a variety of experiments (*e.g.*, Swets, 1964).

The present paper applied the signal-detection model to the discrimination of stimulus duration by monkeys. Several experiments (Catania, 1970; Elmsore, 1971; Reynolds and Catania, 1962; Stubbs, 1968) have shown that the duration of a stimulus may be made to function in discrimination situations in a manner similar to other, more commonly studied dimensions of a stimulus, such as its intensity or frequency. None of these studies was done in a way that allows the applicability of signal-detection theory to be evaluated,

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although Stubbs (1968) showed that when the "payoff matrix" for responses in a choice procedure was altered, the subjects' response bias changed.

METHOD

Subjects

Two adult rhesus monkeys, with experimental histories (e.g., Coleman, Liebold, and Boren, 1969), weighing about 7.0 kg each, lived in separate cages, and subsisted on a daily diet of 75, 0.75-g Noyes banana pellets and one whole piece of fruit (apple, orange, or banana).²

Apparatus

One wall of each animal's cage contained three stainless steel levers spaced 7.25 in. (18 cm) apart at a height of 12 in. (30 cm). Each lever was 0.25 in. (0.3 cm) in diameter, protruded 0.5 in. (1.0 cm) into the cage, and required a force of about 1.0 N through a distance of 0.5 cm to operate. Food pellets were delivered into an opening 5 in. (12.0 cm) below the left lever. Water was continuously available through a lip-operated valve mounted in a recess 5 in. (12.0 cm) below the right lever. An in-line display unit was mounted behind a 1-in. (2.54 cm) hole, 2.5 in. (6.0 cm) above the center lever and could be used to produce either a white or a blue stimulus patch. A red pilot light was mounted 2.5 in. (6.0 cm) above each of the side levers and white houselights were mounted overhead. Each cage was enclosed in a light- and sound-attenuating booth that also contained a speaker for providing masking noise. Solid-state scheduling apparatus was used to arrange experimental contingencies, and data were collected on electromechanical impulse counters, printing counters, and a cumulative recorder.

Procedure

At the start of each daily experimental session, white masking noise and a blue stim-

ulus light over the center lever came on. A single press on the center lever changed the light from blue to white. The light remained white for either 100 sec, or some shorter duration, initially 10 sec, with the *a priori* probability of either duration being 0.5. Presses on any lever in the presence of the white light had no effect, and seldom occurred after the first few sessions on this procedure. When the light over the center lever went out, the red pilot lights over each side lever came on. If the white light had been on for 100 sec, a single press on the left lever produced a 0.75-g banana pellet, a 1-sec break in the white noise, offset of the red stimulus lights, and reillumination of the blue light over the center lever. Presses on the right lever following a 100-sec stimulus produced a 10-sec timeout in which all lights and white noise were turned off. Presses on any lever during the timeout reset the 10-sec timer. Following the 10-sec white-light periods, these contingencies were reversed: that is, presses on the right lever were followed by food, and presses on the left lever produced a timeout. Sessions were terminated when 75 pellets had been delivered.

The final baseline procedure was approximated through several steps. After 10 sessions on the above procedure, the probability of food following a correct response was reduced to 0.5. Thus, each correct response produced a brief break in the masking noise, and the opportunity to begin a new trial, but food pellets were delivered only on half of the correct trials, determined by a random probability generator. Twelve sessions later, the brief stimulus duration was increased from 10 to 30 sec. Ten sessions after that, the brief stimulus category was broken into three different durations, with one-third of the brief durations 30 sec, one-third 60 sec, and one-third 80 sec, with the overall *a priori* probability of a brief duration remaining at 0.5. The sequence of durations was determined by a four output random probability generator with only the probability of each duration being predetermined. Thirty sessions later, the final brief stimulus durations of 60, 80, and 90 sec were introduced, with the long duration remaining at 100 sec. Thus, at this point, 50% of the trials were 100-sec trials, at the end of which presses on the left lever were reinforced. The other 50% of the trials were divided equally among 60-, 80-, and 90-sec trials fol-

²In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care", as promulgated by the Committee on the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Academy of Science-National Research Council.

lowing which presses on the right lever were reinforced. Throughout the entire experiment, the probabilities of the three short durations were equal to one another and summed to one minus the probability of the 100-sec duration.

After performance stabilized on the above baseline, the probability of a 100-sec stimulus was manipulated from 0.50 to 0.25, 0.75, 0.33, and 0.67. Each probability remained in effect for at least 12 daily sessions and until the data appeared to be stable. Actual numbers of sessions for the 0.50, 0.25, 0.75, 0.33, and 0.67 probability conditions were respectively 40, 12, 12, 15, and 14. *A posteriori* probabilities for each stimulus value were calculated for the final five sessions on each *a priori* probability value, and the standard deviation of a *posteriori* probabilities from the scheduled values was found to be 0.0134.

RESULTS

Data from the last five sessions on each condition were pooled for analysis. Figure 1 shows the psychometric functions obtained for each animal at each probability. At all values, the choice behavior of both animals showed clear control by the stimulus duration, but the functions differ in both slope and absolute level. The different functions, then, represent different degrees of response bias. In an attempt to describe more adequately and account for this bias, a signal-detection analysis of the data was made.

In the terminology of signal-detection

theory, one of the two stimuli in a discrimination experiment is designated the signal, and the other, noise. Thus, when the subject's task is to report the occurrence or non-occurrence of a signal, there are four possible outcomes on any given trial. That is, the subject may say there was or was not a signal and the signal may or may not have been presented. A correct signal detection is designated a hit, and an incorrect report of a signal is designated a false alarm. The basic function of the theory of signal detection is the receiver operating characteristic or ROC curve, which is obtained by plotting the probability of a hit as a function of the probability of a false alarm. A given ROC curve is generated by altering a biasing variable while holding the variables thought to determine discriminability constant. Thus, the ROC curve is usually thought of as an isodiscriminability curve. In most cases, empirical ROC curves are straight lines when plotted on normal-normal coordinates, (*e.g.*, Blough, 1967).

In the present case, the 100-sec duration was arbitrarily called a signal, and the shorter durations were each considered a different value of noise. A response on the left lever is thus equivalent to reporting the occurrence of a signal. Figure 2 shows three ROC curves for each animal, plotted on normal-normal coordinates. Each curve represents data from one noise duration, shown in parentheses, as a function of data from the signal or 100-sec duration. Each point is from a different probability value, and is the per cent of responses occurring on the left lever following the 100-sec stimulus (hits) as a function of the per cent of responses on the left lever following the shorter duration (false alarms). The straight line ROC curves are least-squares fits to the Z-scores of the data points. Thus, while the manipulations of a *priori* probability of stimulus presentation were effective in altering the distribution of responses to the two levers, the level of discriminability of the durations remained relatively constant, as the points from the different probability conditions fall on or near the same regression line.

Fig. 1. Percentage of responses on the left lever as a function of stimulus duration. The number above each curve represents the probability of presentation of the 100-sec stimulus.

DISCUSSION

The fact that the duration of the white light exerted powerful control of the monkey's choice behavior in all conditions of the

Fig. 2. Operating characteristics for both animals, plotted on normal-normal coordinates. The straight lines are least-squares fits to the Z-scores of the data. Points where 0% of the responses occurred on either lever are not plotted, since such scores cannot be represented on normal-normal coordinates.

present experiment strengthens the assertion that the duration of a stimulus can, through the appropriate operations, be made to function similarly to other dimensions of the stimulus. Some of the conditions necessary for establishment of control of behavior by stimulus duration have been studied elsewhere (Elsmore, 1971), but certainly this area is in need of further experiment.

The response bias of the monkeys in the present experiment was clearly altered by the manipulations of *a priori* probability of reinforcement. There are several possible mechanisms for this effect. The theory of signal detection proposes that the subjects' "criterion" for reporting a signal underlies the observed shift in response bias, and the criterion is assumed to be a function of the expected value of the various response outcomes (e.g., Green and Swets, 1966; Luce, 1959). However, these hypotheses are not testable because we have no means of measuring the hypothetical internal distributions of response proposed by the theory and thereby empirically determining a criterion that is anything different from the observations we make of behavior. Similarly, we cannot independently determine what the expected value of a certain outcome may be.

An alternative hypothesis states that organisms distribute their responses across available alternatives according to some transform of the relative reinforcement frequencies for the alternatives, the simplest case being a match of relative response frequencies and relative reinforcement frequencies. (Herrnstein, 1970; Nevin, 1969) In the present case, there was in fact good matching between relative response and reinforcement frequencies for a given lever. However, this relationship is probably trivial, since it can be shown that matching is an inevitable consequence of many different biases across a good portion of the possible range of variability. This is a consequence of the ratio-like characteristics of the reinforcement schedules for responding on either lever.

Another possibility is that bias is controlled by maximization of reinforcement probability. This hypothesis was investigated by comparing the data with optimal bias levels for producing maximization of reinforcement probability. The optimal bias values were derived from the fitted curves of Figure 2. Given these curves and the conditions of the experiment, it was possible to carry out an iterative procedure whereby the optimal bias value in terms of reinforcement probability, could be determined for each *a priori* probability condition. (Appendix.) The results are shown in Figure 3. The solid line in each frame shows the optimal percentage of responses on the left lever, and the points, the actual overall percentage of responses that occurred on the left lever. The data are reasonable fits to the theoretical functions, with the greatest

Fig. 3. Comparison of optimal bias for maximizing reinforcement rate and obtained response bias for all conditions of the experiment.

deviations being on the order of 10% at the lowest two *a priori* probability values for Stu.

While it is quite clear that relative reinforcement frequency is extremely important in controlling response bias in some types of choice procedures, notably concurrent interval schedules (Herrnstein, 1970), it appears that, at least in the present case, optimization of absolute reinforcement frequency is also important.

APPENDIX

DETERMINATION OF OPTIMAL BIAS VALUES

When the probabilities of presenting the various durations were altered, the ROC curves represented by the fitted lines of Figure 2 were generated. Given any set of stimulus probabilities, the points representing the same stimulus duration tended to fall on the same line. Given a particular set of duration probabilities, it would have been possible for response biases to vary over a wide range, with the points still falling on the same ROC curves; however, different biases would result in different overall probabilities of reinforcement.

Optimal bias values for maximizing reinforcement probability in each condition of the present experiment were determined by a two-step procedure. The first step for each condition was to determine the probability of being correct for the possible range of hit percentages and the associated false alarm percentages. For example, inspection of Figure 2 shows that for a 50% hit rate, Lou had false alarm rates of 1%, 11%, and 30% for the 60-, 80-, 90-sec durations. By substituting these scores into the following formula the probability of a correct choice could be computed for a given set of *a priori* duration probabilities:

$$p_c = p_{100}(p_{H1t}) + p_{90}(1 - p_{FA} |_{90}) + p_{80}(1 - p_{FA} |_{80}) + p_{60}(1 - p_{FA} |_{60})$$

Where p_{100} , p_{90} , p_{80} , and p_{60} are the *a priori* probabilities of the various durations, p_{H1t} is the conditional probability of a response on the left lever given a 100-sec duration, and $p_{FA} |_{x0}$ are the conditional probabilities of a response on the left lever given one of the shorter durations, in other words, the various false alarm rates. For the case cited above, Lou's probability of being correct given a 50% hit rate and an *a priori* probability of 0.5 for the 100-sec duration would be computed:

$$p_c = 0.5(0.5) + 0.167(1 - 0.01) + 0.167(1 - 0.11) + 0.167(1 - 0.30) = 0.68$$

$$0.167(1 - 0.30) = 0.68$$

This procedure was repeated for all possible hit rates, and the hit rate producing the maximum probability of being correct determined. Given this optimum hit rate, the response bias, or per cent of responses on the left lever could be determined by substituting these optimal hit and false alarm rates into the following formula:

$$p_{RL} = p_{100}(p_{H1t}) + p_{90}(p_{FA} |_{90}) + p_{80}(p_{FA} |_{80}) + p_{60}(p_{FA} |_{60})$$

This procedure was repeated for each animal for each of the *a priori* probability values and the results plotted as the solid functions of Figure 3.

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