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INDEPENDENCE OF STIMULUS DISCRIMINABILITY FROM ABSOLUTE RATE OF REINFORCEMENT IN A SIGNAL-DETECTION PROCEDURE

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Three experiments are reported in which two pigeons were trained to detect differences in stimulus duration under varying levels of absolute rate of reinforcement. Two red stimuli, differing in duration, were arranged probabilistically on the center key of a three-key chamber. On completion of the center-key duration, the center-keylight was extinguished and the two side keys were illuminated white. Correct responses were left-key pecks following the shorter duration and right-key pecks following the longer duration. In Experiment 1, relative rate of reinforcement for correct responses was held constant and absolute rate of reinforcement was varied in seven conditions from continuous reinforcement to a variable-interval 90-second schedule. In Experiment 2, relative rate of reinforcement was manipulated across three different absolute rates of reinforcement (continuous reinforcement, variable-interval 15-second, and variable-interval 45-second). Stimulus discriminability was unaffected by changes in absolute or relative rates of reinforcement. Experiment 3 showed that discriminability was also unaffected by arranging the same consequences (three-second blackout) for unreinforced correct responses and errors.

Key words: signal detection, generalized matching law, stimulus discriminability, absolute reinforcement, pecking, pigeons

Behavior on concurrent schedules of reinforcement is well described by the generalized matching law (Baum, 1974):

$$\frac{P_1}{P_2} = c\left(\frac{R_1}{R_2}\right)^a, \qquad (1)$$

where P tallies the number of responses emitted and R tallies the number of reinforcers obtained on two (subscripts 1 and 2) concurrently available schedules of reinforcement. The parameter a is the sensitivity of behavior to changes in the obtained reinforcement ratio, and c is inherent bias, a constant preference across all reinforcement ratios. In concurrent-schedule research, preference is a function of the relative rate of obtained reinforcement (e.g., de Villiers, 1977), but is independent of overall rate of reinforcement if obtained relative rate of reinforcement is constant (Fantino, Squires, Delbrück, & Peterson, 1972).

The generalized matching law (Equation 1) has also been used to describe behavior in a signal-detection task (Davison & McCarthy, 1980; Davison & Tustin, 1978). Davison and Tustin (1978) applied the generalized matching law to the standard signal-detection 2 by 2 payoff matrix and derived two independent measures of performance: stimulus discriminability (or, the ability of a subject to tell two stimuli apart) and response bias. The matrix of events in a signal-detection yes-no procedure is shown in Figure 1. In the presence of one stimulus (S_1), left-key responses (correct responses) are reinforced and right-key responses (errors) have no consequence or, perhaps, produce blackout. In the presence of S_2, right-key responses are correct and are reinforced, and left-key responses are errors and are not reinforced. The various measures are designated P_w and P_z (correct responses) and P_x and P_y (errors), and the reinforcers obtained in the correct cells are R_w and R_z.

Davison and Tustin (1978) wrote two separate equations for performance in S_1 and in S_2. In S_1,

$$\log\left(\frac{P_w}{P_x}\right) = a_{r_1}\log\left(\frac{R_w}{R_z}\right) + \log d + \log c, \qquad (2)$$

and in S_2,

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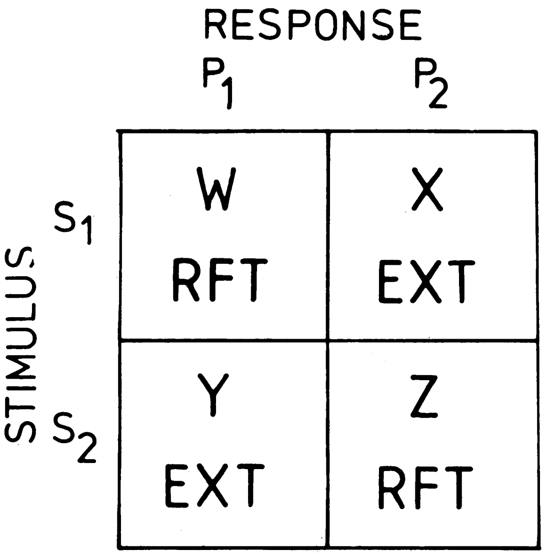

		RESPONSE	
		P_1	P_2
STIMULUS	S_1	W RFT	X EXT
	S_2	Y EXT	Z RFT

Fig. 1. The matrix of stimulus and response events in a standard yes-no detection task. The numbers of events in each cell are denoted W, X, Y, and Z.

$$\log\left(\frac{P_y}{P_z}\right) = a_{r_2}\log\left(\frac{R_w}{R_z}\right) - \log d + \log c. \tag{3}$$

In these equations, a_{r_1} and a_{r_2} are the sensitivities of the behavior allocation to the reinforcement allocation (as is a in Equation 1), log c is inherent bias (as in Equation 1), and log d is discriminability, the measured ability of the animal to discriminate the two stimuli.

In an experiment in which the relative numbers of reinforcers for left and right correct responses are varied, discriminability can be assessed from Equations 2 and 3. If the data are fit to these two equations, an estimate of log d can be obtained by a simple subtraction of the intercept of Equation 3 (log c − log d) from that for Equation 2 (log c + log d) and division by 2. Alternatively, a stimulus function (McCarthy & Davison, 1980a) may be derived. Subtracting Equation 3 from Equation 2 gives:

$$\frac{1}{2}\left[\log\left(\frac{P_w}{P_x}\right) - \log\left(\frac{P_y}{P_z}\right)\right] = \left(\frac{a_{r_1} - a_{r_2}}{2}\right)\log\left(\frac{R_w}{R_z}\right) + \log d. \tag{4}$$

The intercept of this relation (log d), obtained by linear regression, is a least-squares estimate of discriminability (as is the intercept-subtraction method given above). If, $a_{r_1} = a_{r_2}$, as has been shown to occur in some cases, the slope of the relation is zero. If, however, the behavior measure is a function of the reinforcement ratio, Equation 4 will have a nonzero slope, and it will conform to a nonunit isosensitivity curve in signal-detection theory (McCarthy & Davison, 1980b).

A simplification of Equation 4, which assumes $a_{r_1} = a_{r_2}$, was suggested by Davison and Tustin (1978) to provide a point estimate of discriminability for a single experimental condition. A similar point estimate was suggested by Luce (1959; see also Nevin, Jenkins, Whittaker, & Yarensky, 1982).

$$\log\left(\frac{P_w}{P_x}\right) - \log\left(\frac{P_y}{P_z}\right) = 2\log d,$$

$$\text{or,}\qquad \log d = \frac{1}{2}\left[\log\left(\frac{P_w}{P_x}\cdot\frac{P_z}{P_y}\right)\right]. \tag{5}$$

It is clearly safe to use Equation 5 as a point estimate if, and only if, $a_{r_1} = a_{r_2}$. But the point estimate has to be used for conditions in which no reinforcement variation was carried out. It is clear that the point estimate (Equation 5) will be a measure with more variance than the regression estimate (Equation 4, or Equations 2 and 3).

The only published data on the relation between discriminability and overall rate of reinforcement were presented by Nevin et al. (1982) in their Experiment 2. They reported that discriminability was monotonically related to overall rate of reinforcement. This finding seems incompatible with the generalized matching-law results mentioned above (Fantino et al., 1972) from which the detection equations were derived. It also seems inconsistent with some of our own results in which discriminability remained constant with moderate reinforcement-rate changes (e.g., McCarthy & Davison, 1979). The procedure used by Nevin et al. was more complex than the situations we used here. It was a conditional-detection procedure in which a tone signaled a high-reinforcement-rate detection trial and a noise signaled a low-reinforcement-rate trial. In 11/12 cases, point estimates of discriminability were lower on noise trials than on tone trials. Reinforcement rates were varied from variable-interval (VI) 45-sec to VI 225-sec for correct responses, and, using probabilistic schedules, from $p = .04$ to $p = 1.0$ per correct response. The present experiment was a systematic replication of the Nevin et al. study in which overall rate of reinforcement (using VI schedules) was varied in a simpler, nonconditional, detection procedure, and effects on stimulus discriminability were assessed.

EXPERIMENT 1

METHOD

Subjects

Two experimentally naive homing pigeons, numbered 02 and 03, served. Both birds were maintained at 85% ± 10 g of their free-feeding body weights by providing supplementary food in the home cage after each experimental session. Water and grit were available at all times in the home cage.

Apparatus

The experimental chamber, situated remotely from solid-state control equipment, was sound attenuated, and masking noise was provided by an exhaust fan. The chamber contained three response keys, 2 cm in diameter, 9 cm apart, and 25 cm from the grid floor. The center key was transilluminated by a red or white light. The two outer keys were transilluminated white. Illuminated keys were operated by pecks exceeding .1 N. A food magazine was situated beneath the center key and 10 cm from the grid floor. During reinforcement, access to wheat, the keylights were extinguished and the food magazine raised for 3 sec. Apart from the key and magazine lights, the only other source of illumination in the chamber was a houselight.

Procedure

The birds were initially magazine trained and autoshaped to peck all three keys with various key colors. The birds were then trained to discriminate between two stimulus durations under seven experimental conditions. The sequence of conditions and the number of sessions training given in each are shown in Table 1.

In all conditions, the center key was initially lit by a white light, and the two outer keys were dark. A peck on the center key extinguished the white light and produced a red center-key light for one of two durations. The shorter duration, designated S_1, was 2.23 sec. The longer duration, designated S_2, was 3.15 sec. Red center-key responses had no consequence. The probability of occurrence of S_1 relative to S_2 on the center key was constant at .5 throughout the experiment.

On completion of the center-key stimulus, the red light was extinguished and the two white side keys were illuminated. Following S_1 trials (when the shorter stimulus was presented on the center key), a peck on the left key was correct. Following S_2 trials (when the

Table 1

Experiment 1: Sequence of experimental conditions and the number of sessions training given in each. All times are in seconds and the probability of occurrence of the stimuli was .5 for all conditions. Also shown are the number of responses emitted and the number of food reinforcers obtained on the left and right keys on both S_1 and S_2 trials. These data were summed over the last five sessions of each experimental condition.

		Responses in S_1		*Responses in S_2*		*Reinforcers*		
Condition	*Bird*	*L*	*R*	*L*	*R*	*L*	*R*	*Sessions*
1. CRF	02	134	2	20	116	134	116	33
	03	129	7	28	121	129	121	19
2. VI 7.5	02	110	139	14	255	70	180	39
	03	218	9	48	213	123	127	24
3. VI 15	02	265	16	13	290	107	143	22
	03	356	7	5	358	116	134	16
4. VI 30	02	557	63	179	451	137	113	31
	03	686	69	195	573	126	124	17
5. VI 45	02	788	23	153	685	126	124	40
	03	1062	53	446	773	131	119	18
6. VI 60	02	828	86	112	765	117	133	34
	03	1447	55	271	1296	115	135	22
7. VI 90	02	750	206	45	949	102	148	24
	03	2077	86	273	1891	119	131	30

longer stimulus was presented on the center key), a peck on the right key was correct. Incorrect responses were left-key pecks following S_2 presentations and right-key pecks following S_1 presentations.

When a correct response was emitted on either the left or right key, the side-key lights were extinguished and the magazine light was presented for 3 sec. The frequency with which food delivery accompanied the magazine light was varied across seven experimental conditions (Table 1). For example, in Condition 1, 3-sec access to wheat always accompanied the magazine light (continuous reinforcement, CRF). In Condition 6, on the other hand, food delivery accompanied the magazine light according to a VI 60-sec schedule on all correct responses. Incorrect responses always produced 3-sec blackout during which the key- and houselights were extinguished and responses were ineffective. A new trial (that is, presentation of the white center-key light) began after either food reinforcement, magazine light, or blackout had been produced. Throughout the experiment, the occurrence of S_1 and S_2 on the center key was independent of accuracy on the previous trial (a noncorrection procedure).

Experimental sessions were conducted seven days a week. Daily training sessions continued until either 50 food reinforcers had been obtained or 45 minutes had elapsed. Sessions started and ended in blackout. The data collected were the number of responses emitted on the left and right keys following presentations of S_1 and S_2 and the number of food reinforcers obtained on the left and right keys. Experimental conditions were changed when each bird had met a specified stability criterion. The criterion required that the median proportion of correct responses emitted over five sessions be within 5% of the median from the preceding five sessions. This criterion had to be met five, not necessarily consecutive, times.

RESULTS AND DISCUSSION

The number of responses emitted and the number of food reinforcers obtained on the left and right keys on both S_1 and S_2 trials are shown in Table 1. The changing maximum rate of food reinforcement arranged by the schedules is reflected in the changes in the number of correct responses emitted per reinforcer obtained in the various conditions. With continuous reinforcement, for example, one correct response per reinforcer was emitted. With VI 45-sec scheduling, on the other hand, the birds emitted, respectively, 5.9 and 7.4 correct responses. The total number of responses per reinforcer for the two birds, respectively, ranged from 1.09 and 1.14 for CRF to 7.81 and 17.24 for VI 90-sec. Almost invariably Bird 03 emitted more responses, and more correct responses, per reinforcer.

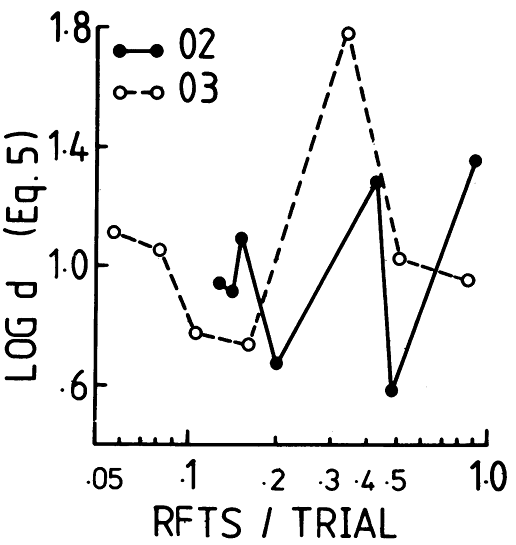

Fig. 2. Experiment 1: Point estimates of stimulus discriminability as a function of the obtained number of food reinforcers per trial. The discriminability estimates were obtained using Equation 5 with the data shown in Table 1.

Figure 2 shows point estimates of discriminability obtained from Equation 5. These have been plotted as a function of the obtained number of reinforcers per trial to facilitate comparison with Figure 7 of Nevin et al. (1982). Nevin et al. reported that point estimates of discriminability fell when the number of reinforcers per trial obtained decreased. The present data showed no evidence of this effect, and nonparametric trend tests (Ferguson, 1966) confirmed that no significant trend ($p = .05$) was present in the data from either bird.

Besides the lack of trend, a feature of these data is their extreme variability from condition to condition. Mean log d values averaged across experimental conditions for Birds 02 and 03 were .97 and 1.06. But the associated standard deviations of the mean estimates were .28 and .35, respectively. Point estimates of discriminability obtained from Equation 5 are based on two ratios of behavior measures and are thus highly sensitive to random variations. This effect is especially clear when discriminability is high, that is, when few errors are emitted. The extreme case occurs when no errors of one sort or the other (P_x or P_y; Figure 1) are emitted in a session, and discriminability becomes infinite. Stimulus discriminability was high in the present experiment (noticeably higher than in Nevin et al.'s experiment using apparently identical stimuli), and so the present data may not be sufficiently accurate to constitute a failure of replication of Nevin et al.'s results. Accordingly, in Experiment 2, we attempted to obtain more reliable estimates of discriminability of the two stimuli by varying the relative rates of reinforcement for correct responses at three overall rates of reinforcement and using fits to Equation 4 to provide good estimates of log *d*.

EXPERIMENT 2

METHOD

Subjects and Apparatus

These were the same as in Experiment 1.

Procedure

The procedure in all three parts of Experiment 2 was identical to that used in Experiment 1 except in two regards. First, in each procedure of Experiment 2, the probability of presenting S_1 (short duration) was varied from .2 to .9 (.1 to .9 in Procedure 3) over four experimental conditions. Since reinforcement for correct responses was arranged using CRF or single VI schedules, the stimulus-probability variation resulted in variations in the number of reinforcers obtained for each of the two correct responses (McCarthy & Davison, 1979). Second, three different scheduling arrangements were used in Experiment 2. In the first procedure of the experiment, reinforcement was available for each correct response. In the second procedure, reinforcement was delivered for a correct response on the average once every 45 sec, and in the third procedure, reinforcement for a correct response was delivered on the average once every 15 sec. These procedural details, with the sequence of experimental conditions, are shown in Table 2. Experiment 1 also provided three data sets which were used in the analysis of Experiment 2. These were data from the same arranged overall-reinforcement rates (CRF, VI 45-sec, VI 15-sec) with an S_1-presentation probability of .5 (i.e., Conditions 1, 3, and 5 of Experiment 1).

As in Experiment 1, training on an experimental condition continued until the stability criterion had been met.

RESULTS AND DISCUSSION

The numbers of responses emitted and food reinforcers obtained in each condition are shown in Table 2. Changing the probability of presenting S_1, and hence the relative frequency of reinforcement obtained on the left and right keys, changed the distribution of responses between the two side keys. Changing arranged rates of reinforcement also strongly affected the number of responses per reinforcer and the number of trials per reinforcer. No errors were made in the presence of S_2 by Bird 03 in Condition 1. As a result, these data could not be used in the subsequent data analysis.

Figure 3 shows the results of Experiment 2 plotted according to Equation 4. The data for each bird for the conditions comprising each set of overall rates of reinforcement (including the appropriate data from Experiment 1) were fit using least-squares linear regression. The equations of the best-fitting straight lines, and the standard deviations of the slopes $[(a_{r_1} - a_{r_2})/2]$ and intercepts (log *d*), are shown on each graph. Although the fits of the straight lines shown in Figure 3 are poor, the estimates of log *d* were considerably improved over the point estimates obtained in Experiment 1. In addition, they were very similar to those obtained in Experiment 1. For the two birds the standard deviations for discriminability (log *d*) in Experiment 1 were .28 and .35, respectively, but in Experiment 2 they decreased to less than half these values, .12 and .17. However, even with these improved estimates, Figure 3 shows no evidence of a decrease in discriminability levels with decreasing reinforcement rates: that is, the obtained intercepts were not systematically different across the CRF, VI 15-sec, and VI 45-sec conditions.

A final important feature of the curve fits shown in Figure 3 is that all six slopes were

Table 2

Experiment 2: Sequence of experimental procedures and conditions and the number of sessions training given in each condition. All times are in seconds, and SPP refers to the probability of occurrence of Stimulus 1 (short duration). Also shown are the number of responses emitted and the number of food reinforcers obtained on the left and right keys on both S_1 and S_2 trials. These data were summed over the last five sessions of each experimental condition.

				Responses in S_1		*Responses in S_2*		*Reinforcers*		
Procedure	*Condition*	*SPP*	*Bird*	*L*	*R*	*L*	*R*	*L*	*R*	*Sessions*
1. *CRF*	1.	.2	02	21	34	4	228	21	228	25
			03	3	56	0	247	3	247	19
	2.	.9	02	232	1	6	18	232	18	24
			03	227	1	9	22	227	22	16
	3.	.7	02	178	1	8	72	178	72	26
			03	170	1	5	77	170	77	16
	4.	.3	02	70	17	9	179	70	179	25
			03	48	47	16	202	48	202	19
2. *VI 45*	5.	.7	02	1263	20	63	527	172	78	22
			03	1656	22	189	507	176	74	16
	6.	.2	02	174	92	32	983	36	214	27
			03	304	101	49	1564	41	209	15
	7.	.9	02	1057	1	11	110	227	23	25
			03	2426	28	38	202	227	23	15
	8.	.3	02	374	12	37	872	68	182	24
			03	622	13	116	1346	66	184	15
3. *VI 15*	9.	.7	02	347	32	20	149	166	84	17
			03	553	9	10	251	163	87	15
	10.	.3	02	166	17	11	400	60	190	25
			03	166	39	40	446	66	184	15
	11.	.9	02	592	2	4	71	216	34	25
			03	747	19	15	84	222	28	15
	12.	.1	02	23	56	4	537	7	243	17
			03	44	22	13	543	15	235	16

greater than zero although only two of them (Bird 02 under CRF and under VI 45-sec) reached statistical significance on a criterion of being greater than two standard-deviation units away from a zero slope. These results mean that the sensitivity to reinforcement following presentations of the short duration (a_{r_1}, Equation 2) was always greater than sensitivity following presentations of the long duration (a_{r_2}, Equation 3). This result is equivalent to a finding of a nonunit isosensitivity curve in detection theory (McCarthy & Davison, 1980b), and it has been ascribed to variance in the decision criterion (Wickelgren, 1968). Although its empirical genesis remains unclear, its effect on point estimates of discriminability (taken using Equation 5) is clear.

Consider Figure 4. Assuming a discriminability (log *d*) value of .5 and no inherent bias (log $c = 0$), performance during S_1 and S_2 presentations (Equations 2 & 3) is shown for three different situations on the left side of the figure: (i) reinforcement sensitivity in S_1 equals reinforcement sensitivity in S_2, i.e., $a_{r_1} = a_{r_2}$ (Graph A1); (ii) reinforcement sensitivity in S_1 is greater than reinforcement sensitivity in S_2, i.e., $a_{r_1} > a_{r_2}$ (Graph B1); and (iii) reinforcement sensitivity in S_1 is less than reinforcement sensitivity in S_2, i.e., $a_{r_1} < a_{r_2}$ (Graph C1). The center plots of Figure 4 show the stimulus functions (Equation 4) for these three results. First, when $a_{r_1} = a_{r_2}$ (Graph A1), the slope of the stimulus function is zero (Graph A2). Second, when $a_{r_1} > a_{r_2}$ (Graph B1), the slope of the stimulus function is positive (Graph B2). Third, when $a_{r_1} < a_{r_2}$ (Graph C1), the slope of the stimulus function is negative (Graph C2).

Stimulus discriminability (log *d*) is shown in two ways on these graphs. First, as the

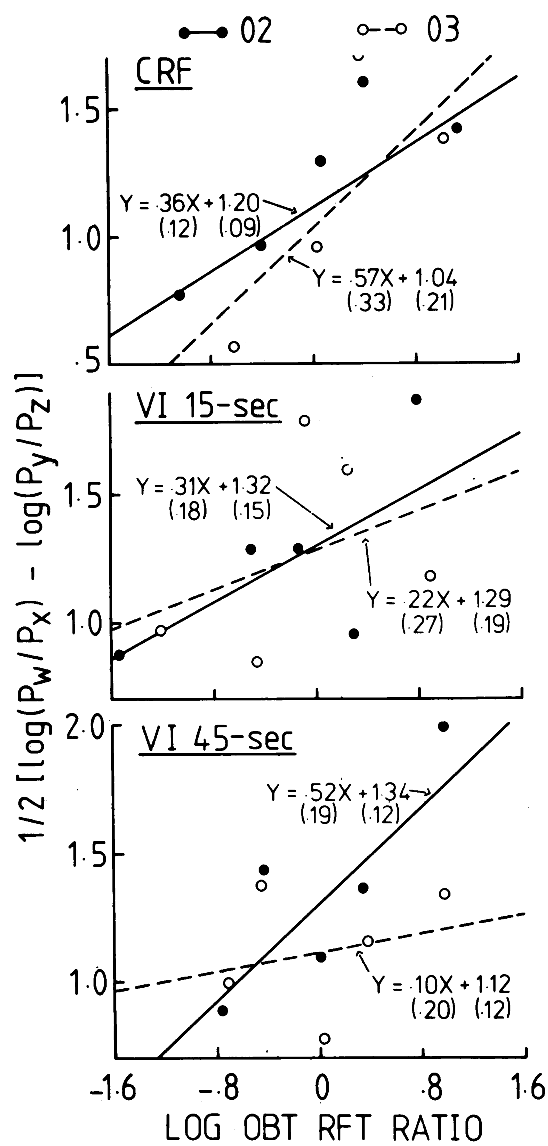

Fig. 3. Experiment 2: The logarithm of the response ratio on S_1 trials minus the logarithm of the response ratio on S_2 trials, all divided by 2, as a function of the logarithm of the obtained reinforcement ratio. The plots correspond with Equation 4. The data shown are for each bird in all conditions comprising each set of overall rates of reinforcement (including the appropriate data from Experiment 1). The best-fitting straight line by the method of least squares, its equation, and the standard deviations of the slope and intercept are shown for each bird and for all three overall rates of reinforcement.

difference between the intercepts of the lines for S_1 and S_2 performance in the left-hand panels, and, second, as the intercepts of the stimulus functions shown in the center panels.

The effect of differing a_{r_1} and a_{r_2} values on discriminability is clear. Obviously, in the first case when $a_{r_1} = a_{r_2}$, reinforcement sensitivity has no effect on log *d*. In the second case, when $a_{r_1} > a_{r_2}$, log *d* will be smaller when the subject is biased toward reporting S_2 [a negative log-reinforcement ratio, log (R_w/R_z)] and larger when the subject is biased toward reporting S_1 (a positive log-reinforcement ratio). In the third case when $a_{r_1} < a_{r_2}$, log *d* will be larger when the subject is biased toward S_2 and smaller when the subject is biased toward S_1.

The right-hand side of Figure 4 shows the corresponding ROC contours, plotted as normal-deviate scores, for each of the three results. First, when $a_{r_1} = a_{r_2}$, an isosensitivity contour with unit slope is obtained, as shown in Graph A3. Second, when $a_{r_1} > a_{r_2}$, the slope of the ROC contour is greater than unity (Graph B3), and third, when $a_{r_1} < a_{r_2}$, the slope is less than unity (Graph C3).

In the present experiment, positive slopes for the stimulus function (Equation 4), shown in Figure 3, mean that the point estimates of discriminability will be smaller when the subject is biased toward reporting the longer duration and larger when it is biased toward reporting the shorter duration. Nevin et al. (1982) did indeed find some extensive and unexplained bias shifts in the presence of noise, which signaled the lower overall rates of reinforcement. But their data cannot be used to assess the presence of unequal sensitivities to reinforcement following presentation of the two stimuli. If the differential sensitivity effect is due to the type of stimuli used and was the same in the Nevin et al. study as here, higher discriminability in the lower reinforcement rate (and more biased) component would be predicted as most biases were toward reporting the short duration. If, of course, in the Nevin et al. data, a_{r_2} was greater than a_{r_1} (Equation 4), then such biases would predict the lower sensitivity they reported. The available data do not allow us to gain closure on these possibilities.

EXPERIMENT 3

This experiment investigated a major procedural difference between Nevin et al.'s (1982) study and the procedure used in Experiments

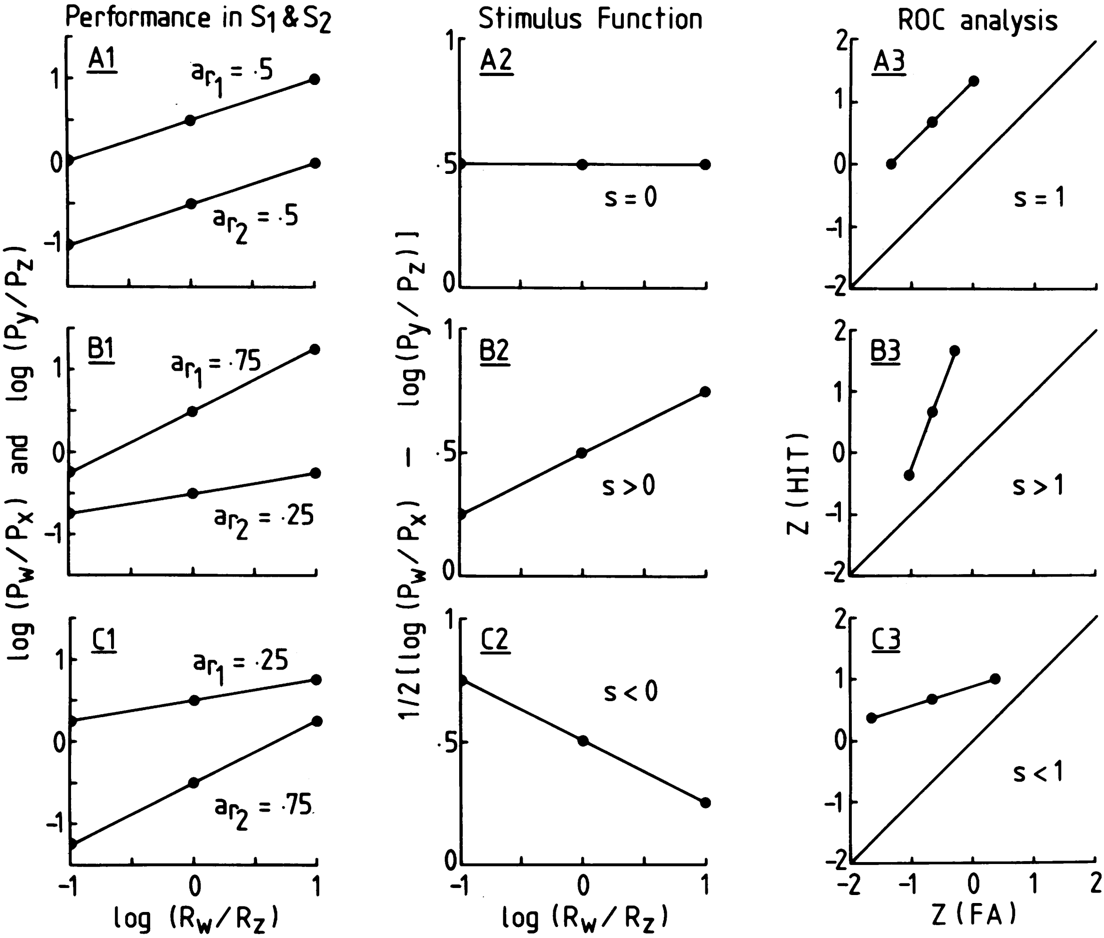

Fig. 4. The relation between relative sensitivity to reinforcement during S_1 and S_2 presentations, the stimulus function (Equation 4), and the detection-theory isosensitivity curve. Graphs A1, B1, and C1 (left panels) show three different reinforcement sensitivities for S_1 and S_2 performance. Graphs A2, B2, and C2 (center panels) show the stimulus functions corresponding to the reinforcement sensitivities given in the left panels, and Graphs A3, B3, and C3 (right panels) the resultant isosensitivity curves. (See text for further explanation.)

1 and 2 here. In the Nevin et al. study, a choice response to one of the two side keys terminated the trial and occasionally produced 3.5 sec access to grain. In other words, unreinforced correct responses and errors had the same consequences, namely, the immediate start of a 6-sec inter-trial interval. In the procedure that we used in Experiments 1 and 2, and have typically used, an unreinforced correct response produces a 3-sec magazine light and an error produces 3 sec blackout before a new trial begins. Perhaps the magazine light in our procedure is acting as a reinforcer and maintaining accurate performance even at low overall rates of food reinforcement. We assessed this possibility in Experiment 3.

METHOD

Subjects and Apparatus

These were the same as in Experiments 1 and 2.

Procedure

The procedure was identical to Experiments 1 and 2 except that unreinforced correct responses now produced 3-sec blackout, the same consequence as for errors. In the five conditions of the experiment, the probability of presentation of S_1 (short duration) was .5, .3, .8, .2, and .7 (Table 3), and performance was stabilized according to the criterion given in Experiment 1 in each condition. A VI 45-sec

Table 3

Experiment 3: Sequence of experimental conditions and the number of sessions training given in each. Correct responses were reinforced according to a VI 45-sec schedule in all conditions. SPP refers to the probability of occurrence of Stimulus 1 (short duration). Also shown are the number of responses emitted and the number of food reinforcers obtained on the left and right keys on both S_1 and S_2 trials. These data were summed over the last five sessions of each experimental condition.

			Responses in S_1		*Responses in S_2*		*Reinforcers*		
Condition	*SPP*	*Bird*	*L*	*R*	*L*	*R*	*L*	*R*	*Sessions*
1.	.5	02	566	6	63	566	118	132	17
		03	947	67	20	1071	95	155	15
2.	.3	02	397	25	61	929	61	189	16
		03	524	84	23	1494	51	199	16
3.	.8	02	1234	15	79	259	211	39	16
		03	1981	15	42	526	186	64	16
4.	.2	02	293	31	136	956	60	190	16
		03	2	421	2	1627	0	250	15
5.	.7	02	1093	19	8	512	153	97	15
		03	1671	80	9	686	161	89	15

schedule arranged food reinforcers for correct responses throughout (as in Experiment 2, Procedure 2).

RESULTS AND DISCUSSION

The number of responses emitted in the four categories and the number of food reinforcers obtained for correct responses are shown in Table 3. Again, the allocation of behavior for both birds followed the relative numbers of reinforcers obtained for left- and right-correct responses. In one condition, $P(S_1) = .2$, the performance of Bird 03 was so extreme that no reinforcers were obtained for responses on the left key. These data have not been used in the analysis of this experiment.

Figure 5 shows the data from Experiment 3 plotted according to Equation 4, with the data fitted by least-squares linear regression. Values of log *d* with relatively small standard deviations were again obtained. Our expectation was that if the magazine light was acting as a reinforcer in Experiments 1 and 2, then under low-reinforcement rates (VI 45-sec), replacing the magazine light with blackout would decrease discriminability. Comparing Figure 5 with Figure 3 shows there was no decrease in discriminability.

The positive slopes of the fitted lines in Figure 5 (significantly greater than zero slope for Bird 03) again show that there was higher sensitivity to reinforcement following S_1 presentations than following S_2 presentations (Graphs B1 and B2, Figure 4).

GENERAL DISCUSSION

Experiment 1 failed to discover any relation between measures of stimulus discriminability and overall rate of reinforcement in a signal-detection task. The data, therefore, did not systematically replicate the results reported by Nevin et al. (1982, Experiment 2). The data collected here in Experiment 1 were point estimates of discriminability from single ex-

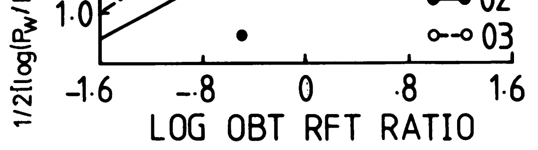

Fig. 5. Experiment 3: The logarithm of the response ratio on S_1 trials minus the logarithm of the response ratio on S_2 trials, divided by 2, as a function of the obtained reinforcement ratio. These plots correspond with Equation 4 using the data shown in Table 3. The best-fitting straight line by the method of least squares, its equation, and the standard deviations of the slope and intercept are shown for both birds.

perimental conditions and were thus quite equivalent to those collected by Nevin et al. Although we can make no statement about the range of reinforcement rates used in the two studies (Nevin et al. used probabilistic, rather than interval, schedules in three of their four conditions), we did use a range of reinforcers per trial (Figure 2) that should have been sufficient to demonstrate a decrement.

The data from Experiment 1 showed considerable variability from condition to condition. Indeed, this variability is predictable from the binomial expansion. Assuming a discriminability (log *d*) value of 1.0, that is, about 91% correct, and assuming a binomial distribution around this percent-correct value, two standard deviations around the true log *d* value can be calculated. These values are from .78 to 1.39 (CRF, number of samples = 250), and the range decreases to .92 to 1.11 (VI 90-sec, number of samples = 2000). The range within which the log *d* values are expected to fall is thus smaller with larger samples, and it is also smaller with lower discriminability values, such as used by Nevin et al. (1982). Although the assumptions underlying this analysis are clearly not met (some data points in Figure 2 fell well outside the two-standard deviation range), the decreasing variance with a greater sample size can be seen in Figure 2. The sample sizes taken here were similar to those taken by Nevin et al., although their samples at high-reinforcement rates (CRF) were larger. With the sampling errors being similar for the points where the present data deviate from those of Nevin et al. (low-reinforcement rates), our data are sufficiently strong to cast doubt on the generality of Nevin et al.'s findings. But, since the Nevin et al. result was the finding of a trend, we may focus some doubt in the present data on discriminability at high- (CRF) reinforcement rates. Perhaps, because of sampling error, these data underestimated discriminability.

Experiment 2 was designed to decrease the sampling error of log *d* at three overall rates of reinforcement, and the results (Figure 3) showed that it did so. But with log *d* values based on five times as many data points as in Experiment 1, there was still no relation between log *d* and overall rate of reinforcement.

The yes-no detection procedure used here is similar in many ways to symbolic matching-to-sample procedures, and the variables that affect matching would be expected to affect detection similarly. The effects of overall rate of reinforcement on some schedules have been reported in this extensive literature (e.g., on fixed-ratio schedules; Ferster, 1960; Nevin, Cumming, & Berryman, 1963), but we can find no clear data concerning overall rate of reinforcement on VI schedules. The changes in accuracy found in matching-to-sample procedures have been ascribed to accuracy decreases in local parts of schedules where the probability of reinforcement is low or zero (Nevin et al., 1963). On VI schedules, however, reinforcement probability is relatively constant at all times and thus, as Carter and Werner (1978) suggested, accuracy may not be affected by overall rate of reinforcement.

Experiment 2 was also instructive in another way. The use of a point estimate of discriminability (Equation 5) has been shown to depend on similar reinforcement sensitivities following S_1 and S_2 presentations (Davison & Tustin, 1978). We have perhaps been erroneous in generally asserting this equality (e.g., Davison & McCarthy, 1980; McCarthy & Davison, 1979, 1980a, 1980b, 1981). Clearly, under some conditions, systematic and significant differences between the two sensitivities may occur, and a point estimate under these conditions is not a reliable measure of discriminability. Indeed, detailed work may necessitate the demonstration of equal sensitivities or, if this is not found, the use of Equation 4 to measure discriminability. Equation 4 defined a measure of log *d*, which we shall call log d_s, which is independent of the sensitivity differences:

$$\log d_s = \frac{1}{2}\left[\log\left(\frac{P_w \cdot P_z}{P_x \cdot P_y}\right)\right] - \frac{\Delta a}{2}\log\left(\frac{R_w}{R_z}\right), \tag{6}$$

where Δa is $a_{r_1} - a_{r_2}$. This measure, log d_s, is the analogue of d_s in detection theory (Schulman & Greenberg, 1970; Treisman, 1976). It equals log *d* under two conditions:

(a) whenever $\log(R_w/R_z) = 0$, and
(b) whenever Δa is zero.

Since, using point estimates only, (*b*) cannot be guaranteed or demonstrated, the only reliable procedure for obtaining point estimates of discriminability is to use a controlled-reinforcement-ratio procedure (McCarthy & Davison, 1980a) to keep the frequency of reinforcement for the two correct choices equal.

To summarize this section, all estimates of discriminability have a sampling error that is decreased by an increased number of observations and also by a decrease in discriminability. Point estimates taken with unequal-reinforcement rates for the two correct choices may be biased because of unequal-reinforcement sensitivities (Figure 4). Since Nevin et al. (1982) did find bias shifts in the lower reinforcement-rate components, it is possible that their discriminability estimates from these components were rather systematically biased. This suggestion is unlikely, though. Their Figure 7 shows, for two birds, that discriminability estimates from a higher reinforcement-rate component were the same as a separate estimate from a lower reinforcement-rate component when these two conditions produced similar reinforcers per trial.

Experiment 3 showed that the production of the same consequences for unreinforced correct responses as for errors did not affect discriminability estimates. This result is consistent with that of Hume (1974), who showed that blackout duration had no effect on discriminability or response bias in an auditory-detection experiment with rats. However, Stubbs and Galloway (1970) found that the provision of a 1-sec magazine light, compared with blackout, increased the accuracy of detection when overall rates of reinforcement were low. This effect was noted on fixed- and variable-ratio, fixed-interval, and differential-reinforcement-of-long-latency schedules. Unfortunately, they did not assess this effect using VI schedules. The finding of similar discriminability in Experiments 2 and 3 here could indicate that the reinforcement rates in Experiment 2 were too high to show the effect of blackout versus magazine light. This explanation, however, is incompatible with Nevin et al.'s (1982) finding that discriminability decreased between continuous reinforcement and VI 45-sec reinforcement for correct responses. Nevin et al.'s finding thus seems at variance with that of Stubbs and Galloway.

The major procedural difference between the present experiment and that reported by Nevin et al. (1982) was the conditional-discrimination procedure used in the latter experiment. In each session, a tone signaled a higher reinforcement-rate trial and noise signaled a lower reinforcement-rate trial. The contingencies and stimuli were identical on each trial. Thus, had the subjects failed to discriminate the conditional stimuli, they would have emitted similar performances on both types of trials. They clearly did not do so, and thus showed at least moderate discriminability between the conditional stimuli. Could the conditional procedure itself have caused the results, perhaps through a contrast-like effect between the two components? There is some evidence in Nevin et al.'s data suggesting an effect of this sort. We calculated point estimates of response bias for each data point (tone and noise separately) using the formula (Davison & Tustin, 1978):

$$\text{log response bias} = \frac{1}{2}\left[\log\left(\frac{P_w \cdot P_y}{P_x \cdot P_z}\right)\right],$$

and divided these by the logarithm of the reinforcement ratio obtained in each session to give a "point estimate" of sensitivity to reinforcement (i.e., $(a_{r_1} + a_{r_2})/2$). The mean reinforcement sensitivity for tone trials was 3.54, whereas the mean for noise trials (lower-reinforcement rate) was .53. The latter value is quite consistent with the literature (e.g., McCarthy & Davison, 1980b) but the former value is extremely high. It indicates that further work on the conditional-detection procedure needs to be carried out before the results from that procedure can be related to those from the standard detection procedure.

Nevin et al. (1982) stressed the need to bring measures of contingency or reinforcement rate into behavioral models of standard (i.e., no-error reinforcement; Davison & Tustin, 1978) detection performance in order to account for their data. Our data do not support this suggestion, and they indicate that behavioral detection models need no modification of this sort. What is evident, however, is that the behavioral model as presently written cannot deal with the data from a conditional-detection procedure and, for this purpose, may need further modification on the lines suggested by Nevin et al. But, when VI schedules are used to maintain detection performance in a simple, standard, detection procedure, our data suggest that overall rate of reinforcement does not affect stimulus-discriminability measures.

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