

INDEPENDENCE OF SENSITIVITY TO RELATIVE REINFORCEMENT RATE AND DISCRIMINABILITY IN SIGNAL DETECTION

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Six pigeons were trained to detect differences between two white stimuli, S_1 and S_2 , differing in duration and arranged probabilistically on the center key of a three-key chamber. Detection performance was measured at two levels of discriminability. At one level, S_1 was five seconds and S_2 was thirty seconds. At the other level, S_1 was twenty seconds and S_2 was thirty seconds. The procedure was a standard signal-detection yes-no design in which stimulus-presentation probability was varied from .1 to .9 at both discriminability levels. On completion of the center-key stimulus, a peck on the center key darkened the center-key light and turned on the two red side keys. A left-key response was "correct" on S_1 trials, and a right-key response was "correct" on S_2 trials. Correct responses produced food reinforcement on a variable-ratio 1.3 schedule. Incorrect responses produced three second blackout. Discriminability was higher for the five-second versus thirty-second conditions than for the twenty-second versus thirty-second conditions, but there were no differences in sensitivity of behavior to reinforcement variation for the two stimulus pairs. Response bias was a function of the relative reinforcement rate for correct choice responses.

Key words: generalized matching law, signal-detection theory, discriminability, response bias, reinforcement, pecking, pigeons

In the standard yes-no signal-detection experiment, a subject is trained to emit one response (e.g., a left-key response) following presentation of one stimulus (S_1), and another response (e.g., a right-key response) following presentation of another stimulus (S_2). The procedure is diagrammed in Figure 1. Here, W , X , Y , and Z refer to the numbers of events in each cell. For example, with P denoting responses and R denoting reinforcements, P_w tallies the number of left-key responses after S_1 presentations, and R_w tallies the number of reinforcements obtained for emitting these responses. In general, correct responses, (P_w and P_z), are reinforced (denoted R_w and R_z , respectively), and incorrect responses, (P_x and P_y) have no consequence (i.e., $R_x = R_y = 0$).

This experiment constitutes part of a doctoral dissertation by Dianne McCarthy. We thank the University Grants Committee for supporting this research through a postgraduate scholarship to Dianne McCarthy and equipment grants to Michael Davison. We also thank the cooperative of Stage 3, Masters and Doctoral students who helped conduct the experiment, and we are indebted to John Milkins and John Tull for their care of the animals. Reprints may be obtained from the authors, Department of Psychology, University of Auckland, Private Bag, Auckland, New Zealand.

Davison and Tustin (1978) viewed this detection task as two concurrent reinforcement-extinction schedules each operating under a distinctive stimulus. Applying the generalized matching law (Baum, 1974) to the detection matrix (Figure 1), Davison and Tustin derived independent measures of stimulus discrimi-

		RESPONSE	
		LEFT	RIGHT
STIMULUS	S_1	W	X
	S_2	Y	Z

Fig. 1. The matrix of stimulus and response events in the present experiment. The numbers of events in each cell are denoted by W , X , Y , and Z .

nability and response bias analogous to those used by signal-detection theorists. First, the generalized matching law suggests that, if the two stimuli, S_1 and S_2 , are indiscriminable, the left-right response ratios in S_1 , (P_w/P_x) , and in S_2 , (P_y/P_z) , will both be a function of the ratio of reinforcements obtained on the left and right keys, (R_w/R_z) . However, as the stimuli become more discriminable, Davison and Tustin reasoned that performance would become progressively more biased toward emitting a left-key response after S_1 presentations, and a right-key response after S_2 presentations. That is, the stimuli in a conventional detection task act as a generalized matching law bias. As biases are constant, additive quantities in the logarithmic form of the generalized matching law, Davison and Tustin wrote two generalized matching law equations to describe choice behavior as a function of both stimulus and reinforcement parameters in the detection paradigm: following presentation of S_1 :

$$\log\left(\frac{P_w}{P_x}\right) = a_{r_1} \log\left(\frac{R_w}{R_z}\right) + \log d + \log c, \quad (1)$$

and, following presentation of S_2 :

$$\log\left(\frac{P_y}{P_z}\right) = a_{r_2} \log\left(\frac{R_w}{R_z}\right) - \log d + \log c, \quad (2)$$

where P and R denote number of responses emitted and number of reinforcements obtained, respectively, and the subscripts refer to the cells of the matrix in Figure 1. The parameters a_{r_1} and a_{r_2} are the sensitivities of behavior to changes in reinforcement ratios.

Two sources of *response bias* are distinguished clearly in the Davison and Tustin (1978) model:

1) *reinforcement bias*, which arises from different numbers of reinforcers for left- and right-key responses (or different magnitudes of reinforcement, etc., McCarthy & Davison, 1979). This is a bias in the sense that a particular left/right reinforcement ratio (R_w/R_z) produces a specific response bias, but, as in the generalized matching law (Baum, 1974), changing the reinforcement ratio will change behavior with a certain sensitivity (a_r). Reinforcement ratio is thus

a biaser in the sense used by signal-detection theorists (McCarthy & Davison, 1979).

2) *Inherent bias*, or $\log c$, which is a constant bias in S_1 or S_2 and may arise from the equipment (e.g., different forces required to operate response manipulandum), or from the subject itself (McCarthy & Davison, 1979). It remains invariant across experimental conditions and stimuli.

Reinforcement bias and inherent bias are collectively termed *response bias* to distinguish them from the bias caused by the physical difference between the two stimuli, S_1 and S_2 . This bias, $\log d$, originally called stimulus bias by Davison and Tustin (1978), we (McCarthy & Davison, 1979; 1980) now term *discriminability*.

The Davison and Tustin (1978) matching model of signal detection, then, assumes that the behavioral effects of discriminability and response bias are additive in logarithmic terms and, hence, there is no interaction between these two variables. Equations 1 and 2 can, therefore, be used to obtain independent measures of discriminability and response bias. We have shown that the reinforcement sensitivities in the presence of each of the two stimuli are equal (i.e., $a_{r_1} = a_{r_2}$; McCarthy & Davison, 1979; 1980). Thus, Equation 2 can be subtracted from Equation 1 to give a measure of discriminability independent of inherent bias ($\log c$), and of reinforcement bias:

$$\log\left(\frac{P_w}{P_x}\right) - \log\left(\frac{P_y}{P_z}\right) = 2 \log d. \quad (3)$$

We have called Equation 3 a *stimulus function* (McCarthy & Davison, 1980) because it relates behavior to discriminative stimuli with inherent and reinforcement biases removed. With discriminability ($\log d$) constant and reinforcement varied, the stimulus function is empirically indistinguishable from the standard signal-detection isosensitivity contour. Such isosensitivity contours show how a subject's distribution of responses between the two alternatives depends upon the bias generated by instructions, stimulus-presentation probability, or the payoff matrix, when the physical properties of the stimuli are held constant (Luce, 1963). Equation 3 is indeed 'isosensitivity', but only when discriminability is constant and reinforcement bias (the rein-

forcement ratio for left and right responses) is varied. It should be pointed out, however, that the only direct prediction of behavior in S_1 and S_2 comes from Equations 1 and 2. The stimulus function (Equation 3) specifies only the relation between the dependent variables. Its use is, of course, in specifying how discriminability is to be measured. A point estimate of *discriminability* is thus given by:

$$\log d = \left(\frac{P_w}{P_x} \cdot \frac{P_z}{P_y} \right)^{1/2} \quad (4)$$

Davison and Tustin (1978) noted that discriminability, as measured by Equation 4, is empirically indistinguishable from discriminability indices used by some signal-detection theorists (e.g., Luce, 1963), and equivalent to that used by others (e.g., Green & Swets, 1966).

Similarly, adding Equation 2 to Equation 1 gives a measure of response bias, a combination of inherent and reinforcement bias:

$$\begin{aligned} \log \left(\frac{P_w}{P_x} \right) + \log \left(\frac{P_y}{P_z} \right) \\ = 2a_r \log \left(\frac{R_w}{R_z} \right) + 2 \log c \end{aligned} \quad (5)$$

Thus, a point estimate of response bias is given by:

$$\log \text{ response bias} = \left(\frac{P_w}{P_x} \cdot \frac{P_y}{P_z} \right)^{1/2} \quad (6)$$

The present experiment was designed to test empirically the Davison and Tustin (1978) assumption of the independence of discriminability and response bias. The biasing effects of changes in the obtained reinforcement ratio on the detection performance of pigeons were examined for both an easy discrimination and a difficult discrimination. The question asked is whether similar values of reinforcement sensitivity (a_r) would be obtained at both discriminability levels. If discriminability is different, but the effects of changes in the obtained reinforcement ratio on behavior are the same, Equations 1 and 2 would yield the same positive slopes for both the easy and the difficult discrimination. Such parallelism would imply, then, that the relation between reinforcement bias and choice behavior was independent of discriminability in signal-detection procedures.

METHOD

Subjects

Six homing pigeons, numbered 141 to 146, served. All birds were maintained at 80% ± 15 grams 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. All birds had experience on a detection task (McCarthy & Davison, 1980) prior to this experiment so no initial magazine, key peck, or schedule training was necessary.

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, 12 cm apart, and 26 cm from the grid floor. Illuminated keys were operated by pecks exceeding .1 N. A food magazine was situated beneath the center key, 10 cm from the grid floor. During reinforcement the key lights were extinguished and the food magazine raised for a nominal 3 sec. No other light was provided apart from the key lights and magazine light.

Procedure

The birds were trained to discriminate between two stimulus durations under eight experimental conditions. The sequence of conditions is shown in Table 1.

Table 1
Sequence of experimental conditions and number of sessions training given in each.

	CONDITION			
	Stimuli		S_1 probability	SESSIONS
	S_1	S_2		
1.	5 sec	30 sec	.1	28
2.	5 sec	30 sec	.7	22
3.	5 sec	30 sec	.3	19
4.	5 sec	30 sec	.9	33
5.	20 sec	30 sec	.7	36
6.	20 sec	30 sec	.3	27
7.	20 sec	30 sec	.9	28
8.	20 sec	30 sec	.1	29
9.*	5 sec	30 sec	.5	30
10.*	20 sec	30 sec	.5	37

*From McCarthy and Davison (1980).

In all conditions, two white stimuli, differing in duration, were arranged probabilistically on the center key. For Conditions 1 to 4 and Condition 9, one stimulus, designated S_1 , was of 5-sec duration, and the other stimulus, designated S_2 , was of 30-sec duration. For Conditions 5 to 8 and Condition 10, S_1 was 20 sec and S_2 was 30 sec. Conditions 9 and 10 were contributed by a prior experiment (McCarthy & Davison, 1980). The probability of occurrence of S_1 on the center key (stimulus-presentation probability) was varied from .1 to .9 as shown in Table 1.

On completion of the center-key stimulus, a peck on the center key darkened the center-key light and turned on the two red side keys. When S_1 had been in effect on the center key, a peck on the left key was defined as 'correct', and when S_2 had been in effect on the center key, a peck on the right key was 'correct'. Correct responses produced a 3-sec magazine light and, according to a variable-ratio 1.3 schedule on all correct responses, this was accompanied by wheat presentation. In this way, the number of food reinforcements obtained on the left and right keys will covary with changes in stimulus-presentation probability. For example, if S_1 probability was .1, then most food reinforcements would be obtained for correct responses on the right key. Incorrect responses (left after S_2 , right after S_1) produced 3-sec blackout during which all chamber lights were extinguished and responses were ineffective.

A new trial, that is, presentation of S_1 or S_2 on the center key, began after either magazine light, food, or blackout had been produced. A noncorrection procedure was used throughout this experiment. The probability of occurrence of either stimulus on the center key was independent of choice accuracy on the previous trial.

Experimental sessions were conducted seven days a week. Daily training sessions continued until either 50 food reinforcements had been obtained or 45 minutes had elapsed. Sessions began and ended in blackout. The data collected were the number of responses emitted on the center, left, and right keys on both S_1 and S_2 trials, and the number of food reinforcements obtained on the left and right keys. Experimental conditions were changed when all birds had met a specified stability criterion five, not necessarily consecutive, times. The criterion required that the median relative

number of responses on S_2 trials over five sessions be within .05 of the median from the prior five sessions.

RESULTS

The number of responses emitted on the center, left, and right keys, and the number of reinforcements obtained on the left and right keys, on both S_1 and S_2 trials are shown in Table 2. The data are summed over the last five sessions of each experimental condition. Observations of the experiment showed that, for all birds and in each condition, center-key responses occurred in a mixed fixed-interval fixed-interval pattern (Ferster & Skinner, 1957). Because a generally high rate of responding was emitted (Table 2), the obtained stimulus duration approximated the arranged duration.

To compare measures of discriminability, $\log d$, between the 5-sec versus 30-sec conditions and the 20-sec versus 30-sec conditions (Table 1), point estimates of discriminability were obtained for each experimental condition and for each bird using Equation 4 with the data shown in Table 2. Figure 2 shows these estimates of discriminability as a function of the logarithm of the ratio of the number of food reinforcements obtained for correct side-key responses, $\log (R_w/R_z)$. The mean value of discriminability, averaged across birds, for the 5-sec versus 30-sec conditions was 1.48, a significantly higher value (Sign test, $p < .05$) than that obtained for the 20-sec versus 30-sec conditions (mean = .39). In addition, a non-parametric trend test (Ferguson, 1966) showed no systematic trend in discriminability as a function of the obtained reinforcement ratio for either the 5-sec versus 30-sec conditions or the 20-sec versus 30-sec conditions.

Choice responses were allocated between the left and right keys on S_1 and on S_2 trials at both discriminability levels as shown in Figure 3. Here, the logarithm of the ratio of the number of responses emitted on S_1 trials, $\log (P_w/P_x)$, and on S_2 trials, $\log (P_y/P_z)$, is shown as a function of the logarithm of the ratio of the number of reinforcements obtained on the left and right keys, $\log (R_w/R_z)$. In order to compare directly sensitivity to reinforcement (a_r) values and discriminability ($\log d$) measures, four sets of data are plotted on each graph. These represent S_1 and S_2 performance

Table 2
 Number of responses emitted on the center, left, and right keys, and number of reinforcements obtained on the left and right keys on both S_1 and S_2 trials. The data are summed over the last five sessions of each experimental condition.

Condition	Bird	Responses in S_1			Responses in S_2			Reinforcements	
		center	left	right	center	left	right	left	right
1	141	55	22	6	10217	2	307	18	232
	142	109	34	2	10798	1	306	25	225
	143	137	36	1	19338	13	287	27	223
	144	51	22	4	7810	17	311	20	230
	145	135	31	2	10691	1	326	26	224
	146	60	30	5	4476	12	304	27	223
2	141	2237	245	1	4594	3	95	179	71
	142	651	236	3	3597	1	101	168	82
	143	1079	242	2	5916	15	95	179	71
	144	1598	260	8	2870	13	85	190	60
	145	1471	239	2	4291	8	97	180	70
	146	558	227	13	2052	5	107	166	84
3	141	1045	113	9	10131	4	226	88	162
	142	246	97	1	7892	11	253	73	177
	143	472	95	1	13321	10	235	80	170
	144	551	103	2	7443	12	237	74	176
	145	608	107	6	8717	1	234	79	171
	146	251	114	10	3277	20	228	81	169
4	141	2926	317	6	1992	2	37	225	25
	142	833	314	3	1262	2	36	227	23
	143	2079	331	6	1177	5	16	236	14
	144	1296	313	1	1029	8	24	233	17
	145	1603	321	3	1446	2	33	225	25
	146	854	308	3	736	3	33	224	26
5	141	5517	293	34	5261	123	30	216	21
	142	4846	308	12	3999	85	43	222	28
	143	5937	268	46	5791	60	74	197	53
	144	6660	299	24	5121	95	44	216	34
	145	4114	247	33	3935	26	101	178	72
	146	2184	271	53	1892	80	63	200	48
6	141	936	47	44	6016	69	152	35	110
	142	1714	106	32	8867	69	222	80	170
	143	1998	95	34	11302	127	196	70	146
	144	1049	60	66	5226	62	239	47	179
	145	924	44	82	6271	52	255	34	196
	146	173	22	40	697	55	89	11	73
7	141	6873	328	17	1694	29	6	245	5
	142	6663	315	6	1925	33	11	245	5
	143	4414	328	18	939	34	2	248	2
	144	6954	300	29	1458	10	26	233	17
	145	3634	311	22	1166	30	17	240	10
	146	2163	324	20	612	36	7	245	5
8	141	251	20	23	10263	92	312	16	234
	142	319	13	15	9365	19	328	9	241
	143	467	29	17	10282	62	302	22	228
	144	312	25	20	7351	34	312	16	234
	145	419	5	37	6058	4	327	2	248
	146	137	10	27	3492	62	325	6	244
9	141	1227	169	6	7411	3	167	119	131
	142	540	151	14	5891	6	180	119	131
	143	818	160	6	11026	9	176	114	136
	144	860	153	8	5813	7	178	119	131
	145	961	169	6	5642	5	170	119	132
	146	500	182	6	3273	20	149	142	108
10	141	3884	170	57	8422	25	195	117	133
	142	4251	214	40	6815	91	126	152	89
	143	4655	177	50	10419	45	180	122	128
	144	3534	181	65	7300	88	162	130	117
	145	2151	144	57	4745	40	188	106	140
	146	1400	191	49	2855	89	122	138	84

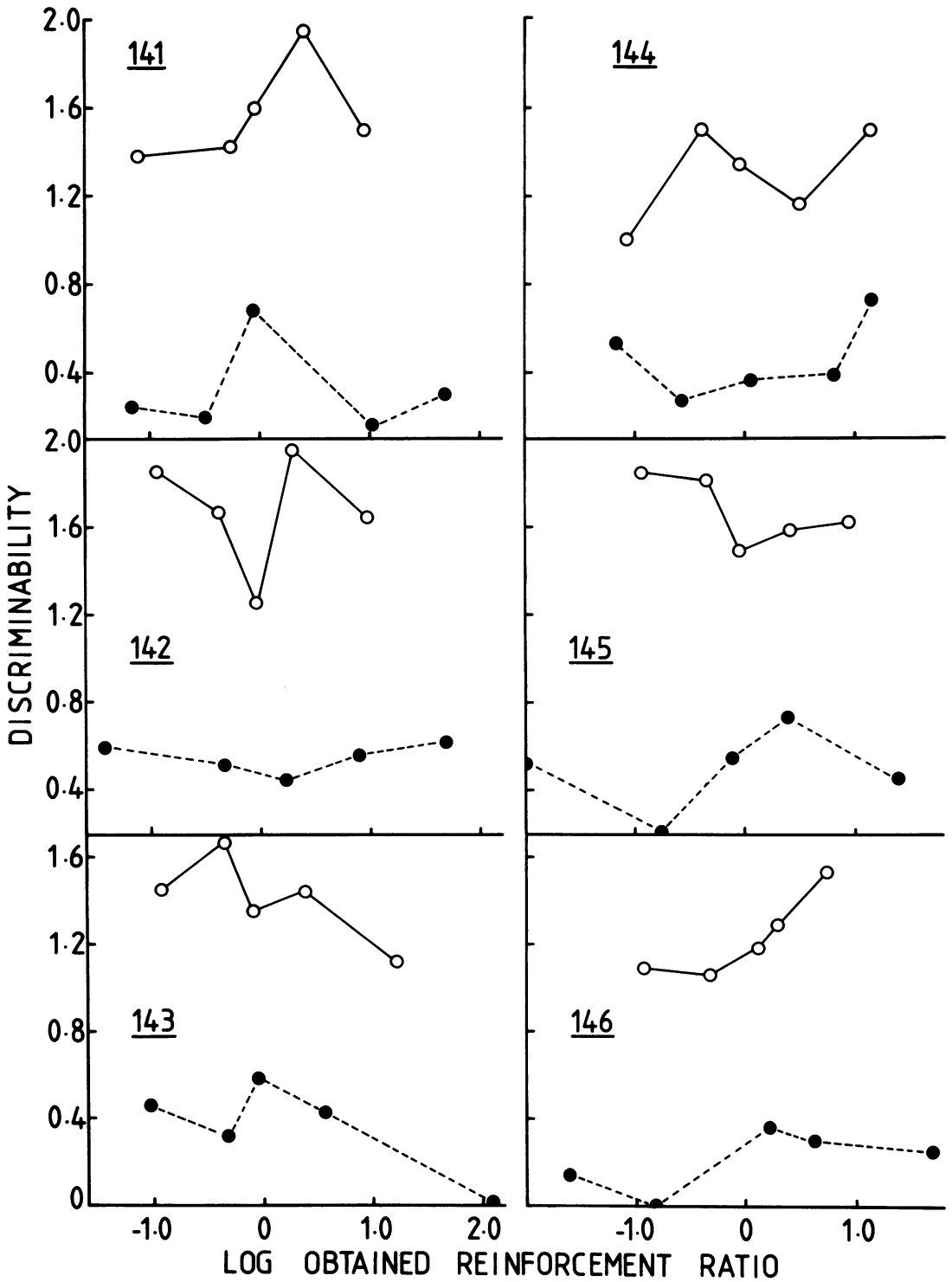


Fig. 2. Point estimates of discriminability (Equation 4) for the 5-sec versus 30-sec conditions (unfilled circles) and for the 20-sec versus 30-sec conditions (filled circles) as a function of the logarithm of the obtained reinforcement ratio. The data were summed over the last five sessions of each experimental condition.

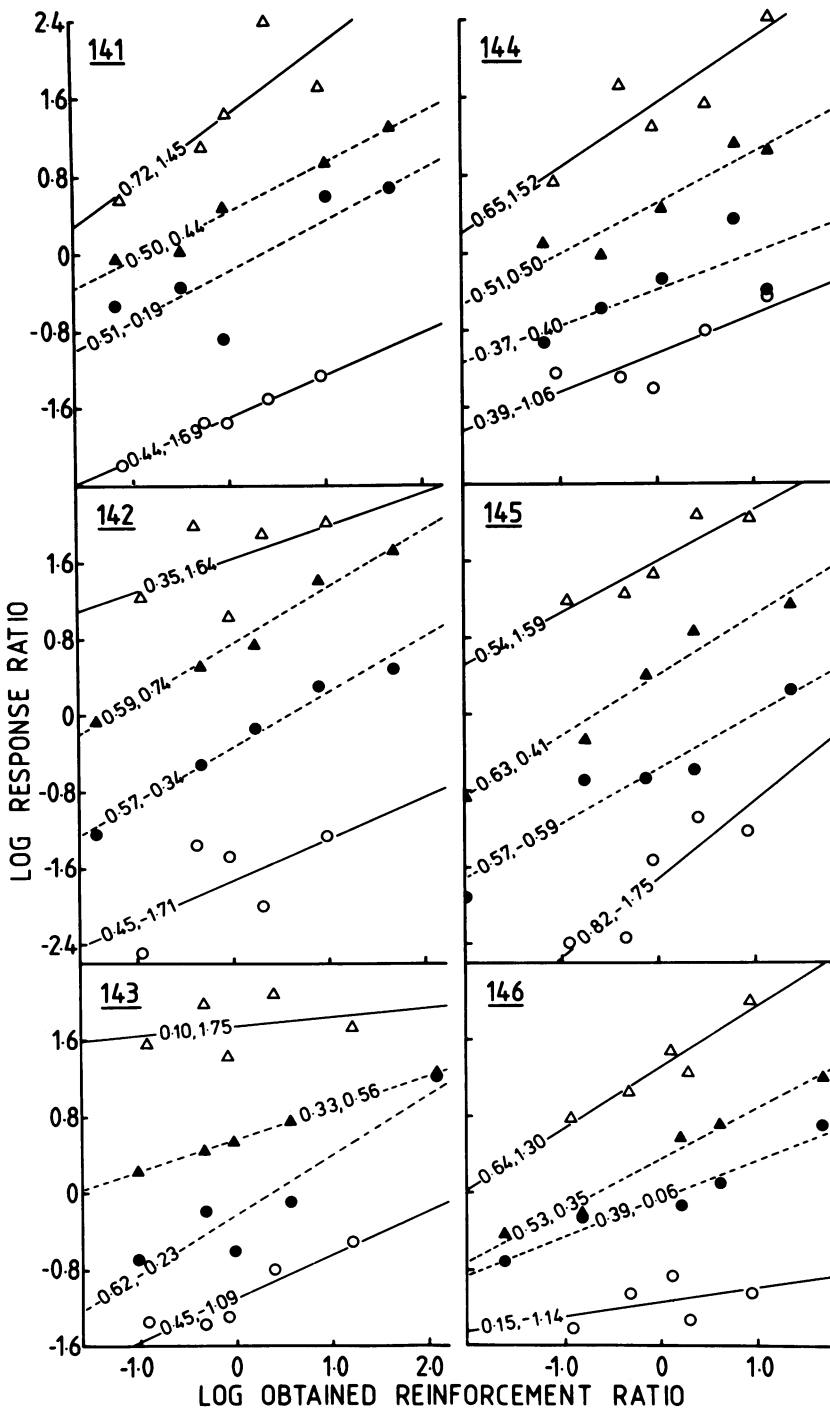


Fig. 3. The logarithm of the ratio of the number of responses emitted on the left and right keys on both S_1 and S_2 trials as a function of the logarithm of the ratio of the number of reinforcers obtained on the two side keys at the two levels of discriminability. These plots correspond with Equations 1 and 2. The unfilled triangles and circles represent S_1 and S_2 performance respectively, for the 5-sec versus 30-sec conditions. The filled triangles and circles represent S_1 and S_2 performance respectively, for the 20-sec versus 30-sec conditions. The best-fitting straight line by the method of least squares is shown for each bird and for each stimulus at both levels of discriminability. The slopes and intercepts are shown, for each bird, on each line. The data were summed over the last five sessions of each experimental condition.

(Equations 1 and 2, respectively) for both the 5-sec versus 30-sec conditions and the 20-sec versus 30-sec conditions (Table 1).

Straight lines were fitted to each set of data shown in Figure 3 by the method of least squares giving values for slope, a_r , the sensitivity of choice behavior to reinforcement rate changes, and composite intercepts, $\log c \pm \log d$, a combination of inherent bias and discriminability. The results of this analysis are shown in Table 3. The slopes and intercepts

Table 3

The parameter a_r , the intercept b_o , their standard deviations (SD), the correlation coefficient (r), and the standard error (SE) of the estimate obtained when Equations 1 and 2 were fitted to the data shown in Table 2 using a least-squares procedure. Five data points were used in each analysis.

Subject	a_r (SD)	b_o (SD)	r	SE
5 sec versus 30 sec				
<i>Equation 1</i>				
141	.72 (.30)	1.45 (.20)	.82	.35
142	.35 (.31)	1.64 (.20)	.54	.35
143	.10 (.19)	1.75 (.14)	.28	.24
144	.65 (.22)	1.52 (.16)	.87	.28
145	.54 (.14)	1.59 (.09)	.91	.16
146	.64 (.13)	1.30 (.08)	.95	.13
<i>Equation 2</i>				
141	.44 (.03)	-1.69 (.02)	.99	.03
142	.45 (.32)	-1.71 (.21)	.63	.36
143	.45 (.10)	-1.09 (.07)	.93	.13
144	.39 (.15)	-1.06 (.11)	.84	.19
145	.82 (.24)	-1.75 (.15)	.89	.27
146	.15 (.16)	-1.14 (.10)	.47	.17
20 sec versus 30 sec				
<i>Equation 1</i>				
141	.50 (.05)	.44 (.05)	.99	.08
142	.59 (.05)	.74 (.05)	.99	.09
143	.33 (.01)	.56 (.01)	1.00	.01
144	.51 (.11)	.50 (.10)	.93	.17
145	.63 (.07)	.41 (.09)	.98	.15
146	.53 (.05)	.35 (.06)	.99	.10
<i>Equation 2</i>				
141	.51 (.19)	-.19 (.20)	.83	.35
142	.57 (.05)	-.34 (.06)	.99	.10
143	.62 (.13)	-.23 (.14)	.94	.24
144	.37 (.19)	-.40 (.17)	.74	.29
145	.57 (.09)	-.59 (.11)	.96	.19
146	.39 (.06)	-.06 (.07)	.97	.12

are shown for each bird on each line in Figure 3. Within birds, the slopes of Equations 1 and 2 for the 5-sec versus 30-sec conditions were not significantly different from each other on a Sign test. The mean slope for Equation 1 (S_1 performance) was .50 and the mean slope for Equation 2 (S_2 performance) was .45. Similarly, for the 20-sec versus 30-sec conditions

there was no significant difference in slope values on a Sign test within birds. Here, the mean slope for Equation 1 (S_1 performance) was .51 and the mean slope for Equation 2 (S_2 performance) was .50. In addition, a Sign test on the 12 pairs of estimates of a_r showed no significant difference in sensitivity to reinforcement between the 5-sec versus 30-sec conditions and the 20-sec versus 30-sec conditions (mean a_r was .48 and .50, respectively).

All birds responded more on the left key on S_1 trials for all conditions (shown by a positive intercept to the fitted lines for Equation 1 in Figure 3), and more on the right key on S_2 trials (shown by a negative intercept to the fitted lines for Equation 2 in Figure 3). The intercepts for S_1 and S_2 performance in the 20-sec versus 30-sec conditions were, of course, lower than those obtained for the 5-sec versus 30-sec conditions because discriminability, shown by the point estimates in Figure 2, was lower in the 20-sec versus 30-sec conditions.

The positive slopes to the fitted lines in Figure 3 imply that response bias changed as the obtained reinforcement ratio varied (McCarthy & Davison, 1979). To show these changes, point estimates of response bias were obtained using Equation 6 with the data shown in Table 2. Figure 4 shows these estimates as a function of the logarithm of the ratio of the number of food reinforcements obtained on the left and right keys for both discriminability levels. A nonparametric trend test (Ferguson, 1966) showed a significant increase in response bias for both the 5-sec versus 30-sec conditions ($z = 3.9$; $p < .01$), and the 20-sec versus 30-sec conditions ($z = 5.3$; $p < .01$), as the obtained reinforcement ratio increased. While bias estimates were similar for the two discriminability levels, the range over which response bias varied was larger for the 20-sec versus 30-sec conditions than for the 5-sec versus 30-sec conditions (Figure 4).

DISCUSSION

Response bias changed as a function of the obtained relative reinforcement ratio for correct detections, but no such trend was seen in discriminability. In addition, sensitivity of behavior to changes in the obtained reinforcement ratio was not a function of the degree of discriminability.

As Equations 1 and 2 yielded the same posi-

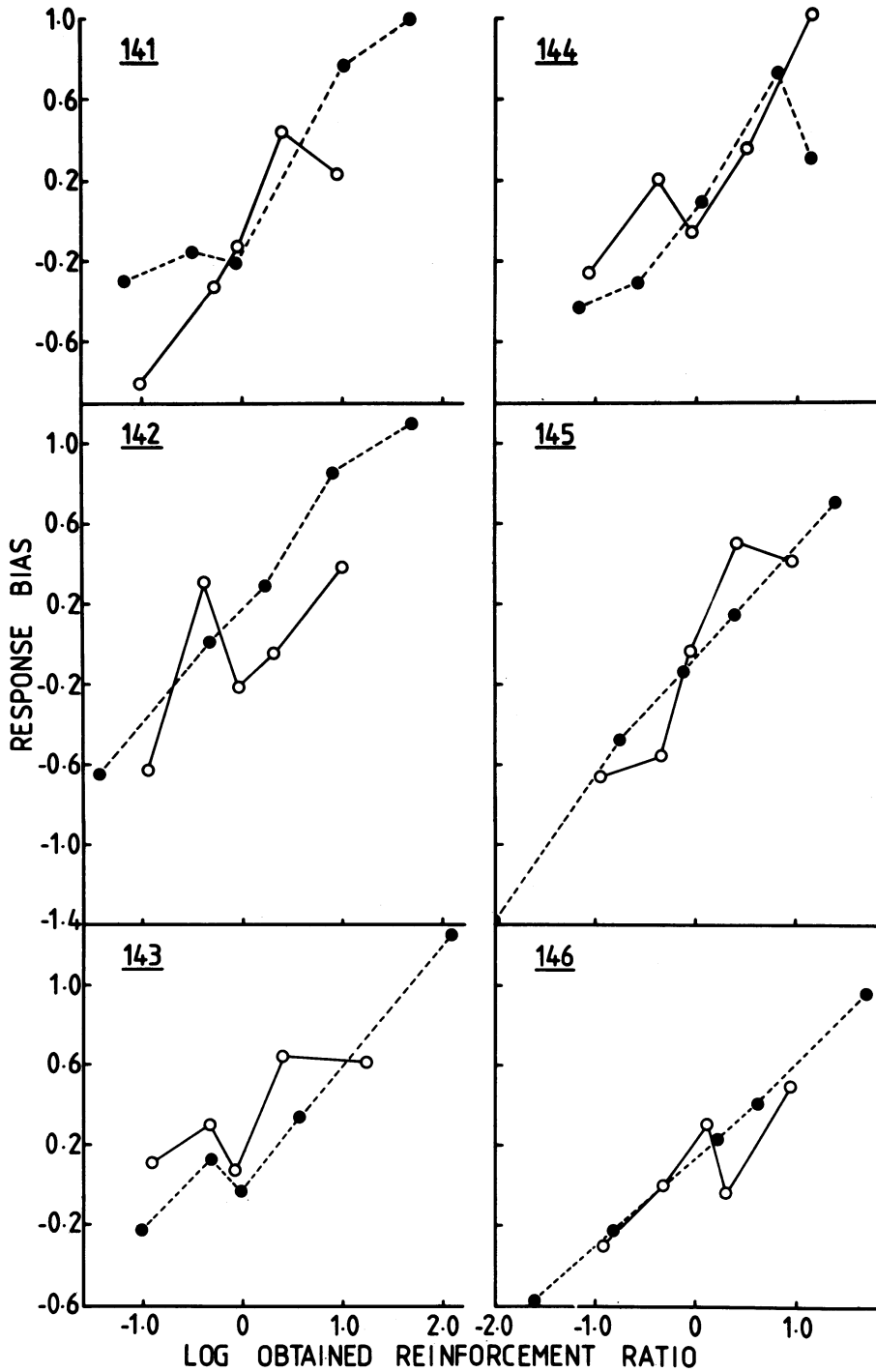


Fig. 4. Point estimates of response bias (Equation 6) for the 5-sec versus 30-sec conditions (unfilled circles) and the 20-sec versus 30-sec conditions (filled circles) as a function of the logarithm of the obtained reinforcement ratio. The data were summed over the last five sessions of each experimental condition.

tive slopes for the two different discriminations, discriminability did not affect sensitivity to reinforcement. Such parallelism also implies that discriminability is constant for all reinforcement bias values. We conclude, therefore, that there was no interaction between discriminability and response bias, and that these two measures are additive logarithmic quantities as proposed by Davison and Tustin (1978) in their matching model of signal detection.

Response bias did, however, vary over a wider range in the 20-sec versus 30-sec conditions than in the 5-sec versus 30-sec conditions (Figure 4). This result is attributable to the use of an uncontrolled reinforcement ratio procedure (McCarthy & Davison, 1980) with resulting deviations of the obtained reinforcement ratio from the ratio of reinforcement rates made available by the set probabilities of stimulus presentation for the difficult discrimination. Thus, in a sense, discriminability did affect response bias because, at extreme stimulus-presentation probability (SPP) values, different estimates of response bias were obtained for the two discriminations. If, therefore, response bias is seen as a result of SPP manipulations, as is typical in signal-detection theory (e.g., Clopton, 1972; Elsmore, 1972; Galanter & Holman, 1967; Hume & Irwin, 1974; Markowitz & Swets, 1967; Schulman & Greenberg, 1970; Terman & Terman, 1972), rather than of reinforcement frequency variation (McCarthy & Davison, 1979, 1980), we would have concluded that discriminability affected response bias. Figures 3 and 4 would have shown the stimulus-presentation ratio as their x-axes, and would have reported mean slopes of about .80 for the difficult discrimination and .49 for the easy discrimination.

Two important points can be made from these considerations. Firstly, they again underline the importance of recognizing reinforcement frequency, and not SPP, as the effective biaser in detection experiments (McCarthy & Davison, 1979, 1980). Secondly, they confirm the conclusion made by McCarthy and Davison (1980) that constant response bias estimates in experiments which vary stimuli will only result when the obtained reinforcement ratios are controlled and cannot deviate from the value set.

One major concern in signal-detection research has been the shape or slope of empirical isosensitivity contours, and the relation

this variable may have to stimulus parameters. In the normative version of signal-detection theory (Green & Swets, 1966), when the hypothesized distributions stemming from the stimuli which underlie the isosensitivity contour are Gaussian and of equal variance, isosensitivity contours of unit slopes result when plotted on normalized coordinates. Gaussian distributions of unequal variance, Rice and Rayleigh, or exponential distributions, on the other hand, give rise to slopes which depart from unity when plotted on normalized coordinates. Nonunit isosensitivity contours have been frequently found in human psychophysical studies where they have been interpreted as providing information about the transducer function relating physical and sensory continua (e.g., Green & McGill, 1970; Green & Swets, 1966; Jeffress, 1964, 1967, 1968; McGill, 1967; Tanner & Birdsall, 1958; Thijssen & Vendrik, 1968), or to be attributable to the effects of nonsensory factors such as criterion variance (e.g., Treisman, 1977; Wickelgren, 1968). Psychophysical studies with animals, although fewer, also report slopes which deviate from unity (e.g., Hack, 1963; Wright, 1972, 1974).

In the present experiment, similar sensitivities to reinforcement were obtained for S_1 and S_2 performance (i.e., $a_{r_1} = a_{r_2}$) at both discriminability levels, implying a stimulus function, Equation 3 (or equivalently, an isosensitivity function on normalized coordinates) with unit slope. Different sensitivities to reinforcement bias manipulations in the presence of the two stimuli (i.e., a_{r_1} not equal to a_{r_2}) could arise if, for example, different responses were required in S_1 and S_2 . Davison and Ferguson (1978), for instance, found that key pecking was more sensitive to reinforcement change than lever pressing in the pigeon. If a_{r_1} did not equal a_{r_2} , the reinforcement terms in Equations 1 and 2 would also appear in the stimulus function (Equation 3) which would then become:

$$\begin{aligned} \log \left(\frac{P_w}{P_g} \right) - \log \left(\frac{P_y}{P_z} \right) \\ = 2(a_{r_1} - a_{r_2}) \log \left(\frac{R_w}{R_z} \right) + 2 \log d. \end{aligned} \quad (7)$$

Because the reinforcement ratio, R_w/R_z , co-

varies with the stimulus-presentation ratio in the standard signal-detection procedure (McCarthy & Davison, 1979), the relation between the two response ratios would not have a slope of 1.0.

In addition, it has been suggested that when the slope of the isosensitivity contour does deviate from unity, the direction of the deviation may be related to stimulus parameters. For example, it has been found that the slopes of empirical isosensitivity contours may decrease with increases in stimulus magnitude (e.g., Green & Swets, 1966; Hack, 1963; Luce & Green, 1970; Swets, Tanner & Birdsall, 1961; Wright, 1972, 1974). This result has often been interpreted as representing an increase in the variance associated with the stimulus as its magnitude is increased, or it has been explained by assuming the distributions underlying the stimuli to be Rayleigh, Rice or exponential (Green & Swets, 1966). Such slope changes with stimulus magnitude are not, however, invariant findings (e.g., Hume, 1974; Nachmias, 1968; Shipley, 1970).

The present results showed no systematic variation in the slope of the isosensitivity function (Equation 3) as a function of stimulus magnitude. For both the easy and the hard discrimination, the same positive slopes were obtained for Equations 1 and 2 implying, then, identical slopes for Equation 3 at both discriminability levels.

In conclusion, the present experiment has shown that discriminability can be varied widely without affecting sensitivity to reinforcement in a signal-detection experiment. In particular, we have confirmed the assumption of the Davison and Tustin (1978) model, namely, the independence of discriminability and response bias, and supported the finding that variation in response bias is caused by reinforcement frequency changes, rather than stimulus probability manipulation (McCarthy & Davison, 1979).

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Received February 29, 1980

Final acceptance June 13, 1980