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ACCURACY OF DISCRIMINATION, RATE OF RESPONDING, AND RESISTANCE TO CHANGE

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Pigeons were trained on multiple schedules in which responding on a center key produced matching-to-sample trials according to the same variable-interval 30-s schedules in both components. Matching trials consisted of a vertical or tilted line sample on the center key followed by vertical and tilted comparisons on the side keys. Correct responses to comparison stimuli were reinforced with probability .80 in the rich component and .20 in the lean component. Baseline response rates and matching accuracies generally were higher in the rich component, consistent with previous research. When performance was disrupted by prefeeding, response-independent food during intercomponent intervals, intrusion of a delay between sample and comparison stimuli, or extinction, both response rates and matching accuracies generally decreased. Proportions of baseline response rate were greater in the rich component for all disrupters except delay, which had relatively small and inconsistent effects on response rate. By contrast, delay had large and consistent effects on matching accuracy, and proportions of baseline matching accuracy were greater in the rich component for all four disrupters. The dissociation of response rate and accuracy with delay reflects the localized impact of delay on matching performance. The similarity of the data for response rate and accuracy with prefeeding, response-independent food, and extinction shows that matching performance, like response rate, is more resistant to change in a rich than in a lean component. This result extends resistance to change analyses from the frequency of response emission to the degree of stimulus control, and suggests that the strength of discriminating, like the strength of responding, is positively related to rate of reinforcement.

Key words: multiple schedules, reinforcer probability, matching to sample, response rate, resistance to change, key peck, pigeons

Resistance to change of free-operant response rate has been studied extensively in multiple schedules. The usual result is that if the schedule components differ in rate or amount of reinforcement, response rate in the richer component is more resistant to short-term disrupters such as prefeeding, response-independent food during intercomponent intervals (ICI), and extinction (for a review see Nevin & Grace, 2000a). This paper reports that the accuracy of a conditional discrimination is also more resistant to disruption in the richer of two components. If the strengthening effect of reinforcement is identified with resistance to change, as argued by Nevin (1974), the result suggests that the quality of performance—that is, the extent to which it conforms to the different contingencies signaled by different stimuli—may be strengthened by reinforcement in the same way as sheer quantity of performance as measured by response rate.

Research on the resistance to change of response rate in multiple schedules involves stimulus control by the component stimuli but does not evaluate the resistance to change of discrimination. In a standard experiment (e.g., Nevin, 1974), two successive stimuli signal different reinforcer rates on variable-interval (VI) schedules for the same response. The stimuli are chosen to be highly discriminable, such as red and green key lights for a pigeon pecking a key. When performance is disrupted, smaller decrements in response rate occur in the component with the greater reinforcer rate even if baseline response rates are similar in the two components (e.g., Nevin; Nevin, Mandell, & Atak, 1983). This is evidence that the components were in fact discriminated, but gives no information on whether stimulus control of behavior is more or less resistant to disruption as a result of the conditions of reinforcement in the components.

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The effects of different reinforcer conditions on the resistance to change of discrimination performance may be investigated by arranging identical discrimination tasks with different reinforcer probabilities for correct responses, signaled by distinctive stimuli, and then examining changes in the accuracy of discrimination during short-term disruption. Conditional discriminations such as signal detection or matching to sample, with or without delays between sample and comparison stimuli, have been studied extensively in relation to steady-state conditions of reinforcement (for a review see Davison & Nevin, 1999). By contrast, there are very few studies of the resistance to change of discrimination accuracy. In one such study, Nevin and Grosch (1990) trained pigeons on a delayed matching-to-sample (DMTS) task in which reinforcer duration was signaled at the start of each trial. Accuracy was greater on long-duration trials at all delays. When performance was disrupted by injections of sodium pentobarbital, retention-interval illumination, or reduced exposure to the sample, decreases in accuracy were similar in trials with long- and short-duration reinforcers. If anything, accuracy was less affected in short-reinforcer trials, contrary to the usual results with response rate. This study was not designed to examine response rate, however, and it is not obvious that the disrupters it employed (with the exception of sodium pentobarbital) could be used in conventional free-operant multiple schedules.

More recently, Dube and McIlvane (2002) trained people with mental retardation on two-choice simultaneous discriminations in two conditions. The first condition arranged continuous reinforcement (CRF) for correct responses, and the second arranged intermittent reinforcement according to a short variable-ratio (VR) schedule. After subjects met an acquisition criterion in the first part of each session, the discrimination was reversed in the second part, always with CRF. For 8 of 9 subjects, there were more errors during reversals following CRF than following VR, suggesting that discrimination was more resistant to change if established with more frequent reinforcement in the first part of the session. Thus, although they did not arrange multiple schedules and did not examine response rates, Dube and McIlvane's finding is consistent with the usual results with response rates in multiple schedules.

In order to study resistance to change of response rate as well as discrimination performance within subjects and sessions, we adapted a paradigm developed by Schaal, Odum, and Shahan (2000). They trained pigeons on a multiple schedule in which center-key pecks produced DMTS trials in both components. The center key was lighted with the sample color for 2 s, followed by a delay. Comparison stimuli were then presented on the side keys, and a peck to the key of the same color as the sample was reinforced with food. In effect, this was a chain schedule in which initial-link responding was reinforced by a DMTS trial as the terminal link. The components differed in the value of the VI schedule: 20 s in one component, and 120 s in the other. Schaal et al. found that when the delay was increased within DMTS trials, identically in both components, DMTS accuracy decreased to a lesser extent in the VI 120-s component for all 4 pigeons, and response rate decreased relatively less in the VI 120-s component for 3 of the 4 pigeons. The authors were especially interested in the observation that some increases in delay left VI response rates essentially constant despite substantial decreases in DMTS accuracy. For present purposes, however, the critical result is that both response rate and accuracy decreased less in the leaner component. Their response-rate result is opposite to the usual findings with multiple schedules.

At least three factors may account for the difference between the results of Schaal et al. (2000) and the usual findings of resistance-to-change research. First, Schaal et al. examined stable data after at least 20 sessions at each delay, whereas resistance to change has usually been examined when a disrupter is introduced as a probe during one or a few sessions. Second, the reinforcement value of the DMTS trials may have been greater in the VI 120-s component because onset of the sample signaled a relatively shorter delay to reinforcement (cf. delay reduction theory: Fantino, 1977). Third, the increase in the delay is an internal disrupter—that is, it involves changes in within-component contingencies—as opposed to an external disrupter such as prefeeding or intercomponent food that leaves within-component contingencies

unchanged. Several studies have found that the effects of internal disrupters may be independent of the conditions of reinforcement before their introduction (e.g., Cohen, Riley, & Weigle, 1993; Harper & McLean, 1992; Nevin, 1984).

We modified the Schaal et al. (2000) paradigm to make it more similar to multiple chain schedules with the same initial links. Previous studies have found that response rate is more resistant to change in the component in which the initial link is followed by the richer terminal link (for review and data see Nevin, Mandell, & Yarensky, 1981). Specifically, we arranged equal VI schedules to produce zero-delay matching-to-sample trials in two components that differed in the probability of reinforcement for correct matches. After response rates and matching accuracies were stable in both components, performance was disrupted by prefeeding and by intercomponent food in two successive conditions. In a third condition, a delay was introduced between sample and comparison stimuli as a short-term internal disrupter. A fourth condition examined the effects of extinction, which have been reported to leave the accuracy of a simultaneous discrimination unchanged (Nevin, 1967). Thus, we assessed the effects of reinforcer rate on the relative resistance to disruption of both response rate and matching accuracy, within subjects and sessions, in ways that are similar to most resistance-to-change research.

METHOD

Subjects

The subjects were 4 White Carneau pigeons, all with various experimental histories including variations of the procedure described here. They were maintained at 80% of their free-feeding weights, ±15 g, by postsession feeding as necessary. They were housed individually with free access to water and digestive grit in a temperature-controlled colony with a 12:12 hr light/dark cycle. The experiment was conducted during the light phase at about the same time each day.

Apparatus

Four standard Lehigh Valley Electronics pigeon chambers measuring 35 cm long, 35 cm high, and 30 cm wide were used. Three response keys, 2.5 cm in diameter and requiring a force of about 0.1 N to operate, were located on the front panel, 24 cm above the floor. Each key could be transilluminated with red, green, or white light, or with three parallel black lines on a white background. Line orientations covered the range from vertical to horizontal in 22.5° increments. A houselight was located 4.5 cm above the center key and a food hopper was located behind a 5 cm by 5.5 cm aperture 10 cm above the chamber floor. A noise generator and ventilating fans masked extraneous sounds. The experimental contingencies were controlled and data were recorded by a Med-PC® program running on a microcomputer in an adjacent room.

Procedure

Baseline. Two multiple-schedule components, signaled by red or green lights on the center key, alternated regularly. Within each component, center-key pecks turned off the center-key color according to an arithmetic VI 30-s schedule and produced either vertical or tilted lines as sample stimuli, randomly and equally often, on the center key. The sample was extinguished independently of responding after 2 s and the comparison stimuli were presented immediately, one with lines matching the orientation of the sample and the other with lines matching the sample that had not been presented on that trial. Vertical and tilted comparisons appeared randomly and equally often on left and right sides over trials. A single peck to the comparison key that matched the sample orientation extinguished both comparisons and was followed by 2.5-s access to food (pigeon diet pellets), with hopper light on and houselight off, with a probability that depended on the center-key color. Nonreinforced pecks to the matching comparison and pecks to the nonmatching comparison were followed by 2.5-s blackout. The orientation of the tilted line was adjusted individually in an effort to establish intermediate levels of accuracy that were similar across pigeons; the orientations are given in Table 1. During the course of training, it was sometimes necessary to repeat DMTS trials until the pigeon responded correctly. This correction procedure, however, was not in effect during final steady-state sessions or resis-

Table 1

Procedural information for each pigeon. Top: Line tilts employed in DMTS trials throughout the experiment. Middle: Sequence of training and test conditions, and number of sessions of each. Bottom: Amount of food consumed during the three 40 g prefeedings. Note: BL = Baseline; ICI = intercomponent interval. See text for details.

		Pigeon			
		P120	P195	P264	P955
DMTS line tilt		22.5°	22.5°	22.5°	90°
Number of Sessions	BL 1	30	49	30	32
	Prefeeding	5	5	5	5
	BL 2	63	25	29	50
	ICI food	5	5	5	5
	BL 3	48	23	26	25
	3-s delay	5	5	5	5
	BL 4	17	26	43	43
	Extinction	10	10	10	10
Prefeeding Consumption (g)	1	40 g	24 g	40 g	40 g
	2	32 g	35 g	35 g	30 g
	3	37 g	23 g	38 g	31 g

tance tests. One cycle of the procedure is diagrammed in Figure 1.

Multiple-schedule components ended after four matching trials and were separated by a 30-s ICI with houselight on and keys dark. The components differed in the probability of reinforcement for correct orientation matches. For 2 pigeons, red on the center key signaled a reinforcer probability of .80, and green signaled a probability of .20; the colors were reversed for the other 2 pigeons. The center-key color signaling the first component in a session was chosen randomly. Sessions ended after seven presentations of each component (i.e., 56 matching trials in all). For each pigeon, training continued until response rates and matching accuracies were stable in both components for at least ten sessions as judged by visual inspection.

Resistance tests. To examine resistance to change, stable performance was disrupted by prefeeding, intercomponent food, delay, and extinction. Resistance tests were separated by sufficient baseline training to reestablish stable performances for at least 10 sessions. Table 1 lists the number of sessions required for each pigeon.

Prefeeding. Food was given in the pigeons' home cages 30 min before daily sessions. The progression of food presentation was 20g, 30g, 40g, 40g, and 40g over five consecutive days; similar progressions have been used by Nevin and Grace (1999) and Nevin, Tota, Torquato, and Shull (1990) in research on resistance to change of response rate. The amount of food actually consumed was measured and recorded after 30 min. The pigeons rarely consumed their entire prefeeding rations during the final three days; the actual amounts consumed are given in Table 1.

ICI food. During each ICI, the food magazine was presented for 2.5 s, with hopper light on and houselight off, on a random-time (RT) 15-s schedule for five consecutive sessions. This method of assessing resistance to change of response rate has been used extensively since its introduction by Nevin (1974).

Delay. A 3-s delay was introduced between offset of the sample and onset of the comparison stimuli for five consecutive sessions. The center key was lighted with the color signaling the current component during the delay. No previous studies of resistance to change in a short-term test have employed this method, but delay was a critical variable in the steady-state analyses in the similar paradigm of Schaal et al. (2000).

Extinction. Food was discontinued altogether for 10 consecutive sessions, and all pecks to comparison keys were followed by 2.5-s blackouts. Extinction has long served as a test of resistance to change, with results that agree with those of other test methods (see Nevin, McLean, & Grace, 2001).

During all four resistance tests, limited-hold contingencies were arranged to ensure exposure to both components if responding ceased in either component. If no center-key

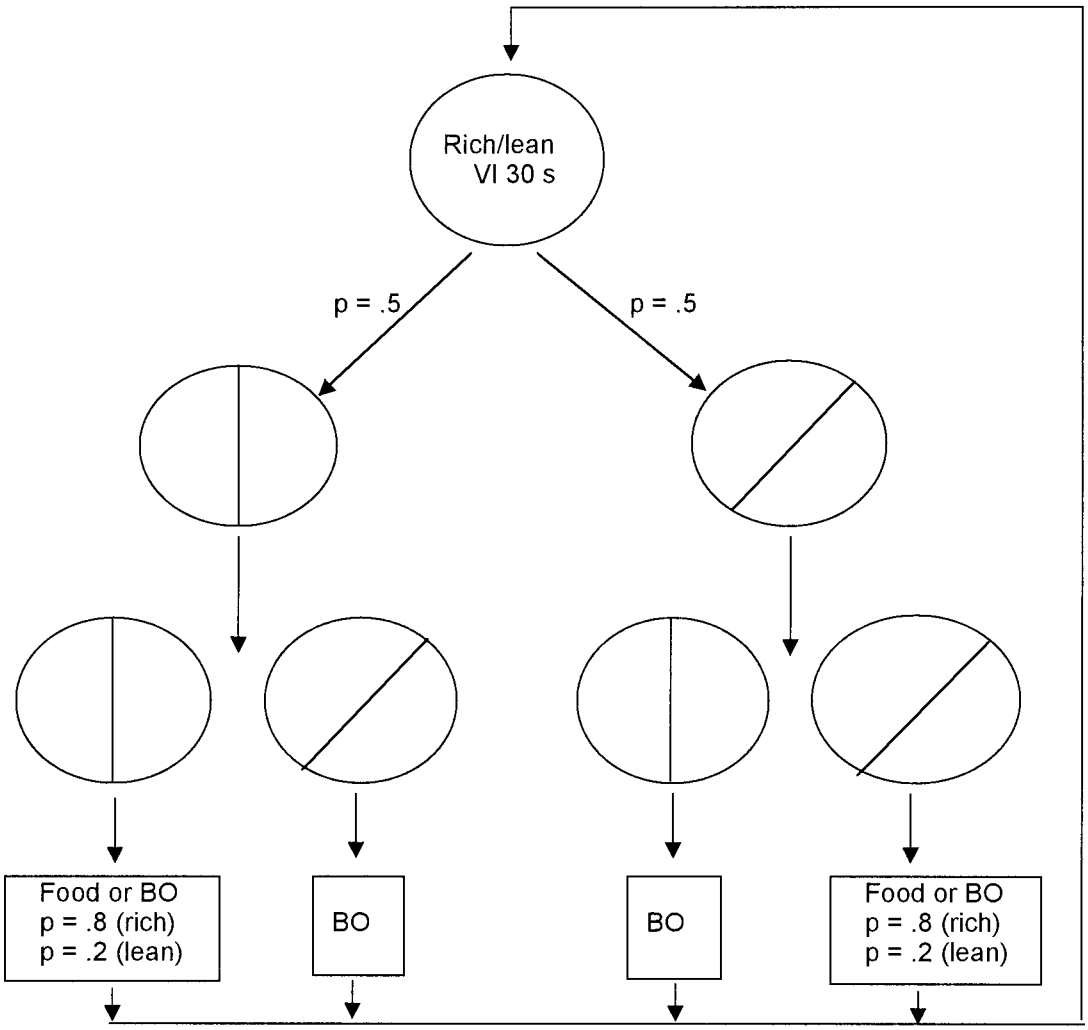

Fig. 1. Schematic diagram of the procedure. Pecks on the center key when it was lighted red or green produced either vertical or tilted lines on the center key according to a VI 30-s schedule. After 2 s, the center key was darkened and the side keys were lighted with lines of matching and nonmatching orientations. A peck on the matching side key produced 2.5-s access to food with probability .8 or .2, depending on the center-key color during the VI phase. Unreinforced pecks to the matching side key and all pecks to the nonmatching side key were followed by 2.5-s blackout. The center key was relighted after food or blackout. See text for further details.

peck occurred within 80 s (the longest VI interval plus 20 s) of component onset or the most recent matching trial, the center-key color was extinguished and a sample orientation was presented independently of responding. If no response occurred to either comparison stimulus within 20 s, the side keys were extinguished, a 2.5-s blackout occurred, and the center-key component stimulus was reinstated. Thus, the procedure provided opportunities for the pigeons to complete either or both links of every cycle within a component and insured that the next component would be available after all limited-hold periods expired.

Measures. In each component, center-key response rate was calculated over the time that the key was illuminated with red or green (i.e., excluding time in matching trials, reinforcement or blackout, or the ICI). In matching trials, the numbers of responses to the vertical or tilted comparisons given vertical and tilted samples were recorded separately. The traditional measure of accuracy, propor-

tion correct or p(C), was calculated from these counts. For the analyses presented below, we also calculated log *d*, a frequently used measure of performance in conditional discriminations such as matching to sample:

$$\log d = 0.5 \log[(Bv|Sv/Bt|Sv)(Bt|St/Bv|St)], \quad (1)$$

where *Bv* is the number of pecks to the vertical comparison and *Bt* is the number of pecks to the tilted comparison, each counted separately for trials with *Sv*, the vertical sample, or *St*, the tilted sample. This measure is the logarithm of the geometric mean of the ratios of correct to incorrect responses on trials with vertical or tilted samples. It may be derived from choice theory (Luce, 1959) and from the generalized matching law (Davison & Tustin, 1978). Moreover, the computing formula for log *d* is closely related to that for differential resistance to change of response rate (Nevin & Grace, 2000b). Unlike p(C), log *d* is independent of biases toward one or the other comparison stimulus, which may occur during disruption by condition changes (e.g., Berryman, Cumming, & Nevin, 1963). Also unlike p(C), log *d* cannot be calculated if any of its terms is zero, as happened occasionally. Accordingly, we added 0.5 to all four response totals for baseline and resistance tests (for rationale see Hautus, 1995). As a result, log *d* has an upper limit. In the present experiment, the maximum value of log *d* in a single session with 28 trials per component is 1.46. When the data are pooled in five-session blocks, the maximum is 2.15.

Because of the differing properties of these measures, we calculated both p(C) and log *d* and looked for ordinal agreement between them. All calculations were based on data pooled for the five sessions of prefeeding, ICI food, delay, the two five-session blocks of extinction, and for the five baseline sessions preceding each resistance test to give comparable sample sizes. For each measure, performance during disruption was expressed as a proportion of the preceding baseline. Because p(C) has a lower limit of 0.50, signifying no control by *Sv* and *St*, we subtracted 0.50 from both baseline and test values of p(C) before calculating resistance to disruption. Thus, the effect of a disrupter is expressed as a proportion of the available range from baseline to 0.50. No such correction is required for log *d* because its lower limit is 0.0.

RESULTS

Data for all pigeons, pooled in five-session blocks, are presented in the Appendix. Baseline performances (Figure 2) and proportions of baseline during resistance tests (Figure 3) are based on these numerical data. Because there are several instances of substantial bias during resistance tests (e.g., Pigeon P264, extinction; Pigeon P955, delay; see Appendix) the figures present log *d* as the measure of discrimination. Values of p(C) are presented together with log *d* in Table 2.

Baseline

Figure 2 presents response rates and log *d* values for the four successive baseline determinations for each pigeon. Response rates were consistently higher in the rich component for all but Pigeon P955, and were reasonably well recovered after each resistance test. These results are entirely in accord with many previous studies of multiple-schedule performance. Matching accuracy was more variable across successive baseline determinations but there were no obvious trends. For each of the four baseline determinations, log *d* was greater in the rich component for 3 of the 4 pigeons; each pigeon provided the exception in one of the conditions. Table 2 shows that these ordinal differences were confirmed by p(C), except that for Pigeon P955, baseline before delay, p(C) was greater in the rich component whereas log *d* was greater in the lean component. If the measure of discrimination was equally likely to be greater or smaller in the rich component, the binomial probability that 12 or more out of 16 comparisons go in the same direction is .011. We conclude that matching was reliably more accurate in the rich component.

Resistance to Change

Figure 3 presents the results for resistance to change, with response rates as proportions of baseline in the left column and log *d* values as proportions of baseline in the right column. Overall, both response rate and matching accuracy decreased relative to baseline

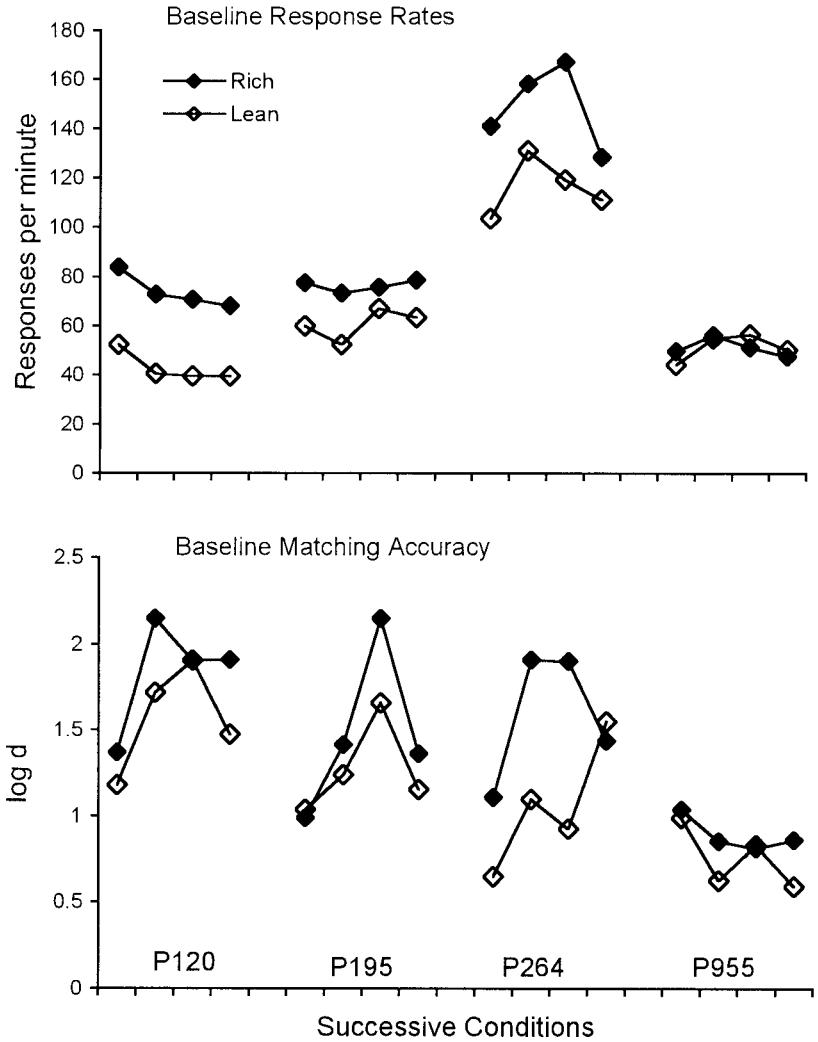

Fig. 2. Top: VI response rates in the rich and lean components pooled over the last five sessions of each successive baseline determination. The data points are given in order and connected for each pigeon. Bottom: Accuracy of matching, measured as log *d*, in the same format.

during resistance tests. Response rate decreased in 39 of 40 cases (4 pigeons, two components, five resistance test blocks), the sole exception being Pigeon P955 in the lean component during the first block of extinction. Matching accuracy measured as log *d* decreased in 32 of 40 cases. As shown in Table 2, there were two ordinal disagreements between log *d* and p(C), but the latter also decreased in 32 of 40 cases. The increases were not consistently associated with a particular disrupter or a particular pigeon. We conclude that our disrupters were generally effective in decreasing accuracy of matching as well as response rate.

We consider differential resistance between rich and lean components separately for each of the resistance tests summarized in Figure 3.

Prefeeding. When responding was disrupted by prefeeding (Figure 3, top), proportions of baseline response rate were greater in the rich component for all pigeons, and proportions of baseline log *d* were greater in the rich component for all but Pigeon P955.

ICI food. When responding was disrupted by feeding during the ICI (Figure 3, second

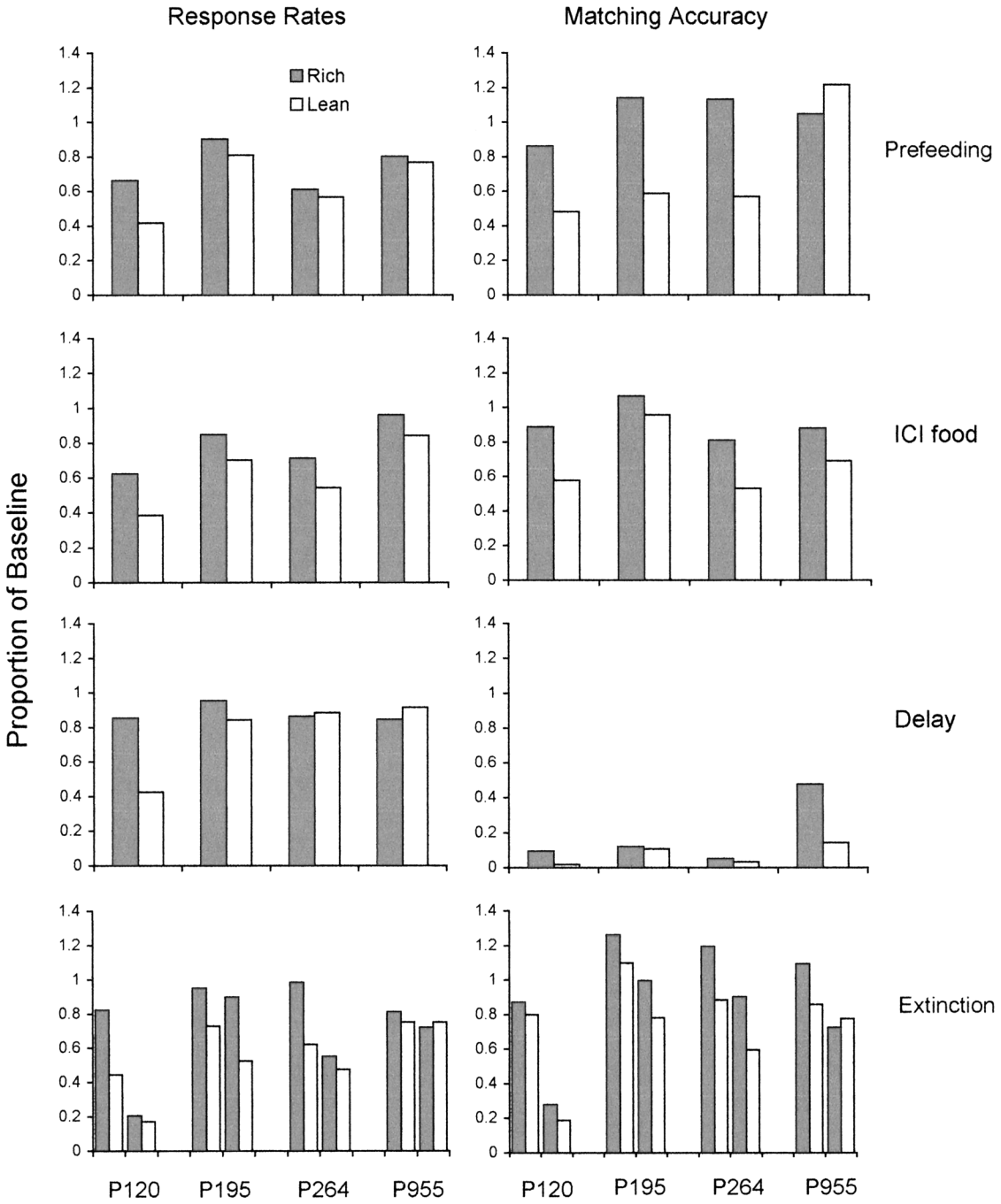

Fig. 3. Top three rows: Response rates and accuracy of matching, measured as log *d*, pooled over five sessions of disruption (by prefeeding, ICI food, and delay) and expressed as proportions of the immediately preceding baseline values for each pigeon. Bottom row: Response rates and log *d* values in two successive five-session blocks of extinction. Note: ICI = intercomponent interval.

Table 2

Two measures of matching accuracy in baseline and during resistance tests. Proportions of baseline during resistance tests are expressed as (px − 0.5)/(po − 0.5) for proportion correct, where po is proportion correct in baseline and px is proportion correct during disruptions. Cases where the measure is not greater by more than rounding error in the rich component are indicated in bold.

		Proportion correct				log d			
		Baseline		Proportion of BL		Baseline		Proportion of BL	
	Condition	Rich	Lean	Rich	Lean	Rich	Lean	Rich	Lean
P120	Baseline	0.957	0.943			1.369	1.180		
	Prefeeding	0.943	0.793	0.969	0.661	1.178	0.569	0.861	0.482
	Baseline	1.000	0.979			2.149	1.717		
	ICI food	0.993	0.907	0.986	0.851	1.907	0.991	0.888	0.577
	Baseline	**0.993**	**0.993**			**1.907**	**1.906**		
	Delay	0.607	0.514	0.217	0.029	0.180	0.035	0.094	0.019
	Baseline	0.993	0.971			1.907	1.476		
	Extinction 1	0.986	0.943	0.986	0.939	1.663	1.179	0.872	0.799
	Extinction 2	0.769	0.658	0.545	0.335	0.531	0.279	0.278	0.189
P195	Baseline	**0.907**	**0.921**			**0.988**	**1.036**		
	Prefeeding	0.921	0.807	1.035	0.729	1.125	0.609	1.138	0.588
	Baseline	0.964	0.929			1.415	1.239		
	ICI food	0.943	0.914	**0.954**	**0.967**	1.508	1.186	1.066	0.957
	Baseline	1.000	0.971			2.146	1.658		
	Delay	0.643	0.600	0.286	0.212	0.255	0.179	0.119	0.108
	Baseline	0.964	0.929			1.361	1.153		
	Extinction 1	0.979	0.936	1.031	1.017	1.716	1.265	1.261	1.098
	Extinction 2	0.964	0.893	1.000	0.917	1.353	0.900	0.994	0.781
P264	Baseline	0.929	0.814			1.107	0.648		
	Prefeeding	0.950	0.707	1.050	0.659	1.252	0.370	1.131	0.571
	Baseline	0.993	0.914			1.907	1.096		
	ICI food	0.979	0.800	0.971	0.724	1.545	0.581	0.810	0.530
	Baseline	0.993	0.900			1.899	0.923		
	Delay	0.557	0.507	0.116	0.018	0.098	0.030	0.052	0.032
	Baseline	**0.971**	**0.979**			**1.437**	**1.548**		
	Extinction 1	0.979	0.957	1.015	0.955	1.717	1.370	1.195	0.885
	Extinction 2	0.943	0.886	0.939	0.806	1.295	0.921	0.901	0.595
P955	Baseline	0.921	0.907			1.036	0.988		
	Prefeeding	0.807	0.921	**0.729**	**1.035**	0.609	1.125	**0.588**	**1.138**
	Baseline	0.879	0.814			0.851	0.626		
	ICI food	0.850	0.736	0.925	0.750	0.748	0.432	0.878	0.689
	Baseline	0.871	0.864			**0.814**	**0.831**		
	Delay	0.671	0.571	0.462	0.196	0.389	0.118	0.479	0.141
	Baseline	0.879	0.793			0.860	0.592		
	Extinction 1	0.879	0.757	1.000	0.878	0.940	0.508	1.093	0.857
	Extinction 2	0.810	0.721	0.819	0.756	0.623	0.459	**0.724**	**0.774**

row), proportions of baseline response rate and proportions of baseline log *d* were greater in the rich component for all pigeons.

Delay. When responding was disrupted by introducing a 3-s delay within DMTS trials (Figure 3, third row), proportions of baseline response rate were greater in the rich component for Pigeon P120 and Pigeon P195, but were greater in the lean component for Pigeon P264 and Pigeon P955. Except for Pigeon P120, lean component, response rates were relatively unaffected by delay. By contrast, matching accuracy fell sharply. Proportions of baseline log *d* were greater in the rich component for all 4 pigeons, although the differences were small for all but Pigeon P955.

Extinction. When responding was disrupted by extinction (Figure 3, bottom), proportions of baseline (for two consecutive five-session blocks of extinction, shown separately), were greater in the rich component for both response rate and log *d*, with the exception of Pigeon P955, second block.

As shown in Table 2, the ordinal differences between accuracy relative to baseline in the rich and lean components found for log *d* were confirmed by p(C) with few exceptions. For Pigeon P264, p(C) was greater in the lean component during ICI food, and for Pigeon P955, p(C) was greater in the rich component, second block of Extinction. Thus, matching accuracy was more resistant to change in the rich component in 18 out of 20 cases for both log *d* and p(C).

Comparing response rates and matching accuracy. The data shown in Figure 3 suggest at least ordinal within-subject agreement between resistance of response rate and resistance of matching accuracy to all disrupters except the 3-s delay, under which response rates decreased relatively little and inconsistently across pigeons but matching was severely disrupted for all 4 pigeons. Figure 4 displays the relation between proportions of baseline log *d,* on the y-axis, and proportions of baseline response rate, on the x-axis. This scatter plot shows that, except for delay, most of the data points fall above the major diagonal. Thus, when a disrupter was applied equally to both the VI and the DMTS portions of each component, matching accuracy was relatively more resistant to change. Equally important, the positive covariation of resistance to change of matching accuracy and response rate (again excepting delay) suggests some commonality in the strengthening effects of reinforcement on these separate aspects of performance.

DISCUSSION

Our experiment arranged a two-component multiple schedule in which free-operant responding produced matching-to-sample trials where correct responses were reinforced with different probabilities. The experiment was designed to determine whether steady-state discrimination accuracy and its resistance to change depended on the conditions of reinforcement in ways that are similar to response rate.

Baseline Performance

Response rate. Individual baseline response rates were consistently higher in the rich component in 3 of the 4 pigeons. Thus, if matching trials are construed as reinforcers differing in effective magnitude because of the different reinforcer probabilities in the components, the difference in baseline response rates is consistent with the usual findings of multiple-schedule research on reinforcer magnitude (e.g., Harper & McLean, 1992). The results are also consistent with previous findings with multiple chain schedules, in that response rates were higher in the initial link with the richer terminal link (e.g., Nevin et al., 1981). Failures to find the usual difference in response rates in 1 or 2 subjects are fairly common in the multiple-schedule literature (e.g., Nevin, 1974).

Matching accuracy. Individual baseline values of log *d* were reliably greater in the rich component. This difference was confirmed by p(C). The finding that matching accuracy was generally greater in the rich component accords with the results of conditional-discrimination and matching-to-sample studies by Nevin, Jenkins, Whittaker, and Yarensky (1982, Experiment 2), Nevin and Grosch (1990), McCarthy and Voss (1995), and Jones, White, and Alsop (1995), all of which signaled different reinforcer conditions within sessions. By contrast, when McCarthy and Davison (1982) varied the reinforcer rate between conditions, they found no effect on accuracy in a signal-detection task. Taken together, these results suggest that different reinforcement conditions must be signaled and presented alternately within a session to have reliable effects on the accuracy of steady-state discrimination.

A general model of conditional discrimination performance advanced by Davison and Nevin (1999) predicts that log *d* will be unaffected by reinforcer rate, probability, or magnitude regardless of the paradigm. It is now evident that their model, and any other model in which discrimination depends on reinforcer ratios but not absolute values, will have to be revised to take account of within-session signaled differential reinforcement.

Resistance to Change

Response rate. Response rate decreased in both components for all pigeons during prefeeding, ICI food, and extinction. With one exception, proportions of baseline response rate were greater in the rich component. These results are consistent with many previous findings for multiple VI VI schedules with

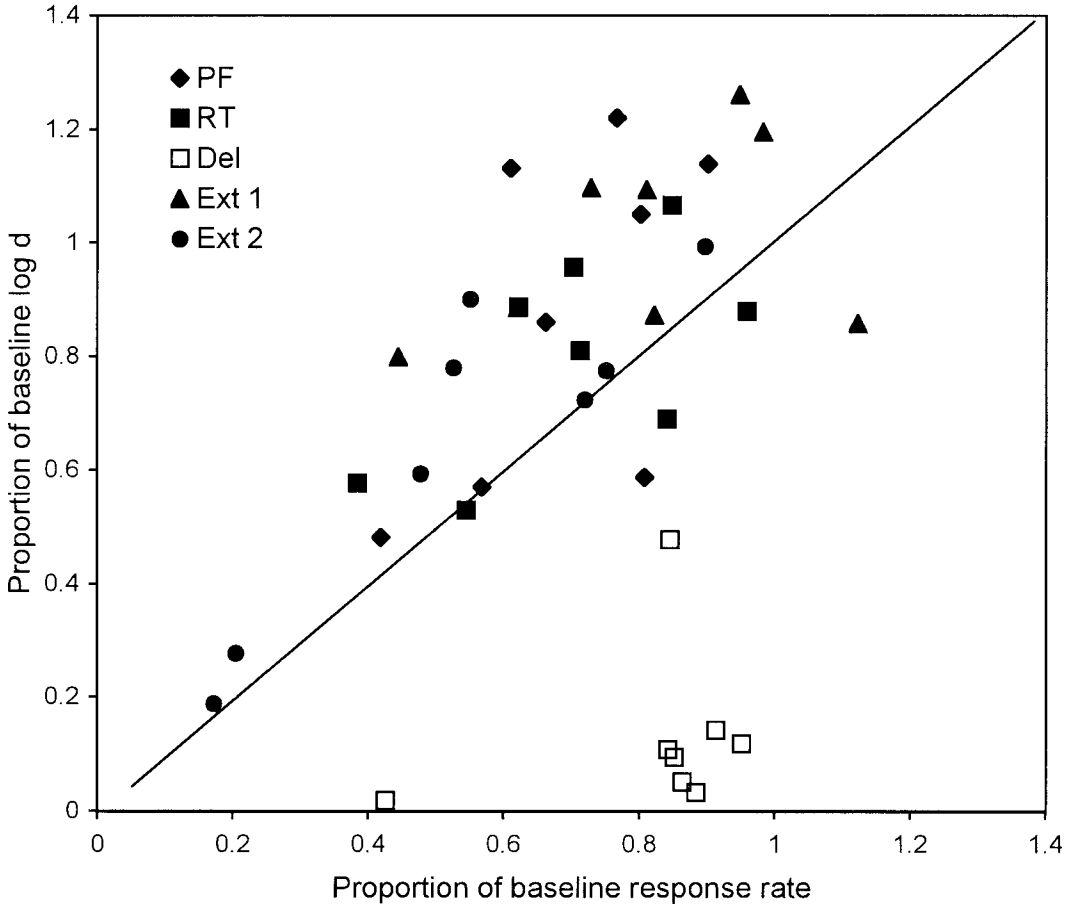

Fig. 4. Resistance to change of matching accuracy as a function of resistance to change of response rate. The y-axis values are from Figure 3, right panels, and the x-axis values are from Figure 3, left panels.

different reinforcer magnitudes (e.g., Harper & McLean, 1992; Shettleworth & Nevin, 1965), and for multiple chain schedules (Nevin et al., 1981). The introduction of a delay between a stimulus produced by a response and the reinforcer following that stimulus has not, to our knowledge, previously served as a disrupter in research on resistance to change of response rate. Here, when a 3-s delay was introduced into matching trials, only Pigeon P120 exhibited a substantial reduction in one component, and response rate was more resistant to delay in the rich component for only 2 of the 4 pigeons. When Schaal et al. (2000) examined the steady-state effects of comparably short delays in a similar paradigm, they also found relatively small and inconsistent effects on response rate in components with different VI schedules.

Matching accuracy. The accuracy of matching, measured as log *d*, generally decreased during all four resistance tests. The ordinal directions of individual changes in accuracy were confirmed by p(C). The abrupt introduction of a delay between the sample and comparison stimuli in matching trials had large and consistent decremental effects on accuracy in both components. Comparable disruptive effects were reported by Berryman et al. (1963) in a study in which all correct matches were reinforced. In our experiment, accuracy was less disrupted by prefeeding, ICI food, and extinction than by delay, but the finding that all three of these disrupters had similar effects was not anticipated. A few previous studies have reported that accuracy in discrete-trial discrimination tasks was decreased by intertrial food presentations. For

example, Wilkie (1984) examined location matching and Spetch (1985) examined color matching in DMTS paradigms. Both studies found that intertrial food decreased the accuracy of DMTS performance. Relatedly, Blough (1998) found that intertrial food decreased the accuracy of successive wavelength discrimination. Extinction and deprivation changes such as prefeeding have not, however, to our knowledge, been reported to decrease the accuracy of discrimination after extensive training. Cumming, Berryman, and Nevin (1965) found that accuracy of DMTS performance was essentially constant during satiation except at the longest delay, where accuracy improved slightly; Nevin (1967) found that accuracy of a simultaneous brightness discrimination was essentially constant during the course of extinction after intermittent reinforcement; and Blough found that wavelength discrimination was unaffected by relatively brief extinction. The present findings of systematic decrements in accuracy with prefeeding and extinction as well as ICI food are at odds with the latter results, and it is worth noting that none of these studies arranged different signaled reinforcement conditions within sessions, as in a multiple-schedule paradigm. Orderly effects on accuracy and its resistance to change may be more likely in multiple schedules, as has been found for response rates (Cohen et al., 1993).

Proportions of baseline accuracy were greater in the rich component with all four disrupters. Although Dube and McIlvane (2002) obtained a related result in a series of discrimination reversals with human subjects, there is no precedent for this result with nonhumans. Nevin and Grosch (1990) failed to find consistent effects of signaled reinforcer duration in a study that examined resistance to disruption of DMTS accuracy, and Schaal et al. (2000) found smaller steady-state decremental effects of increasing delays in their lean component. Because our paradigm was adapted from Schaal et al., it is especially important to address the differences in their results and ours. As described above, Schaal et al. arranged that DMTS trials were produced by responding on a multiple VI 20-s VI 120-s schedule, with reinforcement for all correct matches. As delays were increased over successive conditions, both response rate and accuracy decreased more in the richer (VI 20-s) component; the decreases in accuracy were larger and more reliable. In our data, the introduction of delay as a probe also reduced accuracy more substantially and reliably than response rate, but accuracy decreased relatively more in the leaner component. The difference in the effects of delay on accuracy and response rate in the present study probably resulted from the fact that the intruded delay constituted a major change in the contingencies within matching trials but had little or no effect on the contingencies within the VI segment of each multiple-schedule component. Research is needed to determine how prefeeding, ICI food, and extinction would affect response rate and matching accuracy in the procedure of Schaal et al., where components differed in the length of the VI schedules with the same reinforcer probability for correct matches, as opposed to our procedure where the VI schedules were the same but reinforcer probabilities differed between components. The results should help to delineate the conditions under which response rate and accuracy are more resistant to change in the richer component, and whether the effects are relatively greater on response rate or accuracy.

Excepting delay, the decrements in accuracy of matching during disruption, relative to baseline, were generally smaller than those for response rate when both were expressed as proportions of baseline. This difference might be inherent in the two kinds of performances being measured, the differences between free-operant and discrete-trial performance, or the measures employed to characterize each. Alternatively, it could arise from the fact that our procedure was a chain schedule in which the initial link involved free-operant responding and the terminal link involved matching-to-sample trials. When free-operant response rates are examined in both initial and terminal links of chain schedules, initial-link performance is usually less resistant to change than terminal-link performance (for a review see Nevin et al., 1981). Thus, if the order of the VI and matching links in our procedure were reversed so that correct responses in matching trials produced stimuli signaling food reinforcement for free-operant responding according to VI schedules, there should be greater decre-

ments in matching accuracy than in response rate.

The relation between accuracy and response rate. We interpret the positive covariation in the resistance to change of accuracy and response rate depicted in Figure 4 as a common effect of reinforcement on the strength of discriminating and the strength of free-operant responding. It might also be construed, however, as resulting from the establishment of extended response units. For example, if the pigeons learned discrete response units such as ''peck rich initial-link key–peck vertical sample–peck vertical comparison,'' separate measures of the unit's components would be expected to covary. Moreover, the unit ''peck lean initial-link key–peck vertical sample–peck vertical comparison'' would be more susceptible to disruption because of the lower reinforcer probability. Although the introduction of a 3-s delay had different effects on the first and last members of such units, suggesting dissociation of its components, the argument may have merit for the other three disrupters.

To complete the argument, incorrect units that are never reinforced must also be considered. Presumably, such units draw some strength from generalized effects of reinforcement across units differing in line orientation, as suggested by Davison & Nevin (1999), but because they are never explicitly reinforced, they should be even more susceptible to disruption. Therefore, if disruption reduces unit frequency, incorrect units should be most sharply reduced, with the consequence that measured discrimination accuracy should increase, not decrease. In a directly relevant study, Catania and Dobson (1972, Experiments 2 and 3) intermittently reinforced free-operant oddity-from-sample performance in multiple schedules with concurrent VI reinforcement on a separate key in one component and extinction in the other component. They found that oddity response rates were lower and accuracy was higher in the concurrent VI component, regardless of whether food availability was signaled or unsignaled. Thus, concurrent reinforcement had a greater decremental effect on errors than on correct responses. Accordingly, if concurrent reinforcement is construed as a disrupter that is functionally similar to prefeeding, ICI food, and extinction (e.g., Nevin et al., 1981), unreinforced response units should be more susceptible to disruption in our matching trials and accuracy should increase. Therefore, the consistent decreases in accuracy that we observed are not obviously compatible with the response-unit notion. Whether or not this argument is accepted, the proposed response units are necessarily differentiated by discriminative stimuli, so our results suggest a reduction in control by the stimuli comprising matching trials.

The major result is that when both response rate and matching accuracy were examined within subjects and sessions in multiple schedules, matching, like response emission, was more resistant to change in the component with more frequent reinforcement. If resistance to change is accepted as a measure of strength, the present findings suggest that discriminating between stimuli may be strengthened by reinforcement in the same way as free-operant responding.

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APPENDIX

Responses per minute in the rich and lean VI components and response totals for rich and lean matching trials, both pooled over five-session blocks for individual pigeons in baseline and resistance tests.

		VI component		Conditional discrimination response totals							
		Response rates		Rich				Lean			
Pigeon		Rich	Lean	Bv|Sv	Bt|Sv	Bt|St	Bv|St	Bv|Sv	Bt|Sv	Bt|St	Bv|St
P120	Baseline	83.8	52.5	74	5	60	1	64	5	68	3
	Prefeeding	55.6	22.0	73	5	59	3	47	16	64	13
	Baseline	72.7	40.6	66	0	74	0	71	3	66	0
	ICI food	45.3	15.6	72	0	67	1	63	4	64	9
	Baseline	70.8	39.6	65	1	74	0	64	0	75	1
	Delay	60.4	16.9	35	28	50	27	29	44	43	24
	Baseline	68.1	39.5	68	0	71	1	69	3	67	1
	Extinction 1	56.1	17.6	77	1	61	1	72	3	60	5
	Extinction 2	13.9	6.8	38	19	55	9	38	20	37	19
P195	Baseline	77.6	59.9	57	9	70	4	65	6	64	5
	Prefeeding	70.1	48.5	66	2	63	9	53	14	60	13
	Baseline	73.4	52.5	60	4	75	1	62	9	68	1
	ICI food	62.3	37.0	68	8	64	0	54	11	74	1
	Baseline	75.7	67.1	62	0	78	0	63	0	73	4
	Delay	72.1	56.6	34	32	56	18	32	36	52	20
	Baseline	78.6	63.4	68	3	67	2	65	8	65	2
	Extinction 1	74.6	46.2	64	3	73	0	71	1	60	8
	Extinction 2	70.5	33.3	54	2	81	3	71	9	54	6
P264	Baseline	141.0	103.5	64	7	66	3	43	18	71	8
	Prefeeding	86.2	58.8	56	2	77	5	34	26	65	15
	Baseline	158.2	130.9	73	1	66	0	73	10	55	2
	ICI food	112.8	71.4	56	2	81	1	70	12	42	16
	Baseline	167.1	119.1	83	0	56	1	72	7	54	7
	Delay	144.4	105.4	40	30	38	32	42	23	29	46
	Baseline	128.4	111.0	73	2	63	2	59	2	78	1
	Extinction 1	126.3	68.9	66	3	71	0	62	5	72	1
	Extinction 2	70.7	53.0	73	7	59	1	64	12	60	4
P955	Baseline	49.9	44.3	57	5	60	18	40	31	58	11
	Prefeeding	40.1	34.0	49	9	73	9	56	21	50	13
	Baseline	56.3	54.9	53	6	70	11	64	13	50	13
	ICI food	54.1	46.3	62	8	57	13	43	18	60	19
	Baseline	51.4	56.5	61	10	61	8	53	14	68	5
	Delay	43.5	51.7	64	8	30	38	33	28	47	32
	Baseline	47.6	50.3	46	12	77	5	58	10	53	19
	Extinction 1	38.6	56.5	60	3	63	14	45	23	61	11
	Extinction 2	34.3	37.8	55	15	56	11	44	29	57	10