JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2003, **79,** 289–306 NUMBER 3 (MAY)

*CONTINGENCY DISCRIMINABILITY, MATCHING, AND BIAS IN THE CONCURRENT-SCHEDULE RESPONDING OF POSSUMS (*TRICHOSURUS VULPECULA*)*

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Six possums (*Trichosurus vulpecula*) responded under dependent concurrent variable-interval variable-interval schedules of reinforcement. Over 15 conditions, barley–carob was one reinforcer with the other reinforcer consisting of Coco Pops®, coconut, or a barley–carob mixture with 0%, 2%, 4%, or 6% salt added to the barley. The schedules were both variable-interval 40 s. As has been found with other species, behavior on the concurrent schedules was biased by the type of feed, with the 6% salt and the coconut giving the greatest biases towards the barley–carob mixture. The schedules were varied over 17 conditions using the barley–carob mixture alone or the barley–carob mixture versus the mixture with 4% or 6% salt. Both the contingency-discriminability model (Davison & Jenkins, 1985) and the generalized matching law described the data from the three sets of conditions equally well. Both gave similar measures of bias; however, some of the parameter values found with the contingency discriminability model were uninterpretable. Thus, any argument for this model based on the interpretability of the parameter values becomes weak. It is worth retaining the generalized matching law as a descriptor of such data.

Key words: concurrent schedules, contingency discriminability, matching, food preference, bias, lever press, possum

Behavior under concurrent variable interval (VI) VI schedules of reinforcement is most commonly analyzed using the generalized matching law (Baum, 1974). Expressed logarithmically, it is:

$$\log(B_1/B_2) = a \log(r_1/r_2) + \log c, \quad (1)$$

where B_1 and B_2 represent the number of responses made, or the times spent on the two alternatives, and r_1 and r_2 describe the number of reinforcers obtained from the two alternatives. The parameter (a) is a measure of the sensitivity of behavior to changes in the relative rate of reinforcement, and log c is a measure of bias towards one of the alternatives over and above reinforcer-rate differences.

Undermatching is found when a is less than 1.0; that is, the subject's responding tends towards indifference. Overmatching is indicated by an a value greater than 1.0. Undermatching, with a values usually around 0.8 (Baum, 1979; Davison & McCarthy, 1988; Williams, 1988), is the most common result in studies using a generalized matching law analysis. The size of a has been suggested to be influenced by the discriminability of the schedules (Miller, Saunders, & Bourland, 1980) and other procedural factors (Baum; deVilliers, 1977; Shull & Pliskoff, 1967). Undermatching has been demonstrated in many species (humans: Mace, Neef, Shade, & Mauro, 1994; cows: Foster, Temple, Robertson, Nair, & Poling, 1996; Matthews & Temple, 1979; goats: Foster, Matthews, Temple, & Poling, 1997; horses: Dougherty & Lewis, 1992; rats: Baum; Wearden & Burgess, 1982; hens: Temple, Scown, & Foster, 1995; and pigeons: Davison & Hunter, 1976; Hollard & Davison, 1971).

The second parameter (log c) measures the tendency of a subject to respond more consistently on one alternative, independent of reinforcer-rate differences. This is termed bias. When the two alternatives are similar, any bias thought to be due to a color or position preference is termed inherent bias. Bias, however, can also be experimentally arranged. When studying food preference in cows, Matthews and Temple (1979) suggested two separate sources of bias and a modification of the generalized matching law. In logarithmic form, it is:

$$\log(B_1/B_2) = a \log(r_1/r_2) + \log(q_1/q_2) + \log b, \quad (2)$$

This study formed part of a Ph.D. thesis for the University of Waikato, Hamilton, New Zealand by the first author. The authors wish to thank Tania Signal and Jenny Chandler for help in conducting this experiment and for help in caring for the possums.

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where log b is the inherent bias, q_1 and q_2 are the qualities of the foods, B is as in Equation 1, and log (q_1/q_2) + log b is equal to log c in Equation 1. This equation gives a measure of the degree of any experimentally arranged bias, resulting from different response or reinforcer types, over and above inherent bias. This analysis has been used to examine the bias resulting from different response requirements (Sumpter, Foster, & Temple, 1995; Sumpter, Temple, & Foster, 1998), qualitatively different reinforcers (Foster et al., 1996; Hollard & Davison, 1971; Matthews & Temple, 1979; Miller, 1976), delay to reinforcement (Chung & Herrnstein, 1967), size of the reinforcer (Todorov, 1973), and different noises (McAdie, Foster, & Temple, 1996). The generalized matching law, then, provides a good description of behavior on concurrent VI VI schedules of reinforcement both with and without introduced biasers.

Davison and Jenkins (1985) suggested an alternative to the generalized matching law for describing concurrent-schedule performance; the contingency-discriminability model:

$$B_1/B_2 = c_{cd}(d_r r_1 + r_2)/(d_r r_2 + r_1), \quad (3)$$

where B and r are as in Equation 1, c_{cd} is the measure of bias (similar to c in the generalized matching law), and d_r is the measure of the discriminability of the response-reinforcer contingencies. In other words, d_r measures how well a subject can discriminate as to which of the alternatives the response that gave rise to each reinforcer was made and, therefore, what schedules are in effect. If the subject is unable to make this discrimination, d_r will have a value of 1.0, but as the discriminability of the response-reinforcer contingencies improves, the value of d_r will approach infinity (perfect discrimination). Data which give rise to a values around 1.0 when analyzed using the generalized matching law give d_r values that approximate infinity when analyzed using Davison and Jenkins's contingency-discriminability model. Because undermatching corresponds to a d_r value of less than infinity, this model assumes that any undermatching obtained when data are analyzed using the generalized matching law is actually the result of less than perfect discrimination between the response-reinforcer contingencies.

One limitation of the contingency-discriminability model is that it does not predict, and cannot describe, overmatching. This result can, however, be described using a generalized matching law analysis. Overmatching is reported sometimes, and so any model which attempts to describe behavior under concurrent schedules should have the ability to deal with these data. Davison and Jenkins (1985) attempted to get around this problem in two ways. First, they suggested that models of punishment, such as those proposed by de Villiers (1980) and Farley (1980), could be used in conjunction with the contingency-discriminability model to explain the occurrence of the overmatching found when a changeover requirement is in effect [such as a changeover delay (COD) or fixed-ratio (FR) schedule] and responses during the changeover requirement are not included in the analysis. Davison and McCarthy (1994) gave an equation that does this:

$$B_1/B_2 = \frac{c_{cd}(d_r R_1 + R_2 - w)}{(d_r R_2 + R_1 - w)}, \quad (4)$$

where w is the number of reinforcers lost per minute due to changing over and the other parameters are as in Equation 3. This model described Davison and McCarthy's data well.

Second, Davison and Jenkins (1985) stated that other cases of overmatching are actually the result of statistical error and should be viewed as such. In other words, the true value of a is actually less than or equal to 1.0, but is not found due to chance variation in the data.

Comparisons of the utility of the generalized matching law and the contingency-discriminability model in describing pigeons' performance on concurrent schedules have given mixed results. Davison and colleagues (Davison & Jenkins, 1985; Davison & Jones, 1995; Davison & Jones, 1998; Jones & Davison, 1998) have argued that the contingency-discriminability model provides as good a description of behavior as the generalized matching law. In contrast, Baum, Schwendiman and Bell (1999) analyzed behavior over a wide range of reinforcer-rate ratios, both with and without a COD, and found that the generalized matching law accounted for more variance in their data than the contingency-discriminability model.

Analyses using both the contingency-discriminability model and the generalized matching law show that performance on concurrent schedules ''improves'' as stimulus disparity increases as indicated by increasing a or d_r values (Alsop & Davison, 1991; Davison & Jenkins, 1985). In fact, it is expected that changes in d_r will always follow changes in a, at least over the range of reinforcer-rate ratios usually used (Davison & Jenkins). Why, then, should the contingency-discriminability model be used for describing performance under concurrent schedules? Davison and Jenkins suggested that the parameter (d_r) in their model is conceptually better than the parameter (a) in the generalized matching law because ''sensitivity to reinforcement'' (a) gives no real explanation for why undermatching might occur, whereas decreases in contingency discriminability, or increases in confusability, could lead to poorer ''matching'' by the subject.

Previous research has shown that the generalized matching law appears to cope well with experimentally introduced biasers (e.g., Foster et al., 1996; McAdie et al., 1996; Miller, 1976; Sumpter et al., 1995; Sumpter et al., 1998). However, how the contingency-discriminability model might deal with introduced biases (such as different foods) is an area that has not yet been addressed. Introduced biasers might simply affect c_{cd} (Equation 3) in the same way as suggested for the generalized matching law. Another possibility, however, is that clearly different foods available from separate sources might increase d_r because the response-reinforcer relation should be more discriminable.

One of the aims of this study was to examine how suitable the generalized matching law and the contingency-discriminability model are for describing concurrent VI VI schedule performance. Another aim was to see how well these models account for introduced biasers. Brushtail possums (*Trichosurus vulpecula*) were used as subjects, and so it was first necessary to determine if these animals behave similarly to other animals when exposed to several different concurrent schedules of reinforcement and qualitatively different reinforcers. Possums are marsupials that, although a protected species in their native Australia, are a major pest species in New Zealand (Clout & Sarre, 1997). One reason for using brushtail possums, then, was that little is known about their behavioral abilities, and it has been suggested that such knowledge would be beneficial in attempts to control their population in both Australia and New Zealand (Wynne & McLean, 1999). If possums' responding on concurrent schedules of reinforcement was found to be similar to that of other species, then this procedure might be appropriate for studying their preferences. The second part of the study was to determine if any introduced bias was constant when reinforcer rate was varied, and how well the generalized matching law and the contingency-discriminability model described the data generated.

METHOD

Subjects

Six adult common brushtail possums were used as subjects. Four of the possums were male and 2 were female. The possums were named George, Arthur, Maggie, Timmy, Holly, and Sylvester. All possums, except Maggie, had prior experience on multiple concurrent VI VI schedules of reinforcement (Muir, 1997). Arthur died after Condition 23 and was replaced by Maggie in Condition 26. The possums were maintained at a stable body weight by daily feeding of dock leaves and apples, and by supplementary feeding of pellets (NRM NZ Ltd) when necessary. They were weighed every two weeks to judge the stability of their weights and to ensure that adequate food was being provided. All possums had a constant supply of water.

Because they are nocturnal, the possums were exposed to reverse daylight conditions and this made it possible to conduct experimental sessions during the day. Two standard 100–150-W light bulbs were on between the hours of 8:00 p.m. and 6:00 a.m., simulating daylight. During experimental sessions, which occurred from approximately 8:00 a.m. to 8:40 a.m., two 60-W red light bulbs provided the only illumination in the room. For the rest of the time the room was in darkness. A heater was present in the room and maintained the temperature at an average of 18 °C. Similar maintenance procedures have been used successfully with possum experimental subjects in the past (Hudson, Foster,

& Temple, 1999; Signal, Foster, & Temple, 2001; Signal, Temple, & Foster, 2001).

Apparatus

The subjects' home cages also served as experimental chambers. Each cage, measuring 860 mm by 510 mm by 540 mm, was constructed of galvanized steel grid and had a wood nest box attached to the top where the subjects slept. Access to each of the cages was by way of a plywood door (550 mm by 330 mm) located 70 mm from the floor of the cage. The experimental equipment was also located on the door and consisted of two amber lights (28-V DC) positioned 360 mm from the bottom of the door and 200 mm apart. A slot where a lever could be inserted was located 80 mm below each light. Levers were inserted only during the experimental sessions to prevent damage by the possums. An electronic beeper located at the top and center of the outside of the door provided auditory feedback when an effective response was made on either of the levers. An effective lever press required a minimum force of 0.25 N.

For Conditions 1 through 4, one food magazine was attached to the door of the cage, whereas for all other conditions two food magazines were attached. Each magazine could be raised to present food through a hole (130 mm by 100 mm) in the door 180 mm below the levers, giving access to the food for 3 s. When a magazine was lowered, the subjects were unable to reach the food. The access holes were directly under the levers, and the food in a magazine varied depending on the condition. Steam-flaked barley and carob chips mixed in the ratio of 15:1 was used in most conditions as one of the foods and is referred to here as barley.

All conditions were conducted using a 386 IBM-compatible computer equipped with a MED-PC® interface and software. This was located in the experimental room. The computer collected and stored the experimental data, which were also copied into a data book.

Procedure

Concurrent VI VI schedules were dependently arranged on the left and right levers (Stubbs & Pliskoff, 1969). Interreinforcement intervals were initially calculated for a VI 15-s schedule (an arithmetic series with 15 intervals with the smallest interval 1 s and the largest interval 29 s), and these numbers were adjusted to the size of the required schedule (e.g., for a VI 30-s schedule, each number would be multiplied by 2) and randomly arranged in a series. The starting point within the series was randomly determined prior to the beginning of each session.

At the beginning of each session, following the insertion of the levers, both lever lights were illuminated, and the subjects could respond on either lever. When a response resulted in a reinforcer, the lights were extinguished, and the food magazine was presented for of 3 s. At the conclusion of a reinforcer, the food magazine was lowered, and the lever lights came back on. Whenever a subject switched levers, a 2-s COD began, timed from the first response on the lever. During this time, the subject could respond but no reinforcement was available. Each experimental session lasted for 40 min. Sessions were conducted five days per week.

The experiment consisted of 30 conditions, using a range of VI schedules and feeds. Table 1 shows the order of the conditions and the number of sessions in each condition. In Conditions 5 through 9, the feeds were barley, Coco Pops® and desiccated coconut, and the schedules were equal VI 40-s schedules. In Conditions 10 through 19, the schedules were equal, and various amounts of salt were added to the barley in one or the other magazine. In order to add salt to the barley and ensure an even distribution throughout, the salt was first dissolved in water. The barley and salted water were then mixed and dried in an oven designed for the drying of plant material at 80 °C for approximately 24 hr (or until completely dry). The barley for the 0% salt conditions was simply wet and then dried to serve as a baseline for comparison with subsequent concentrations. This was necessary because after drying, the barley was noticeably harder to chew.

Each condition was in effect until the responding of all possums had reached stability. Stability was determined statistically by calculating the median of the proportion of left responses for each 5-day period and comparing this to the median for the previous 5-day period. Statistical stability was reached when these medians differed by .05 or less five (not necessarily consecutive) times. Stability was

Table 1

The order of conditions, the VI schedules in effect, the food associated with each schedule, and the number of sessions required to reach stability in each condition.

	Schedule(s)		Feeds		
Condition	Left VI	Right VI	Left	Right	Sessions
1	40	40	Barley		26–41
2	22.5	180	Barley		22
3	108	22.5	Barley		29
4	40	40	Barley		37
5	40	40	Barley	Barley	14–27
6	40	40	Barley	Coco Pops	16–37
7	40	40	Coco Pops	Barley	14–20
8	40	40	Coconut	Barley	10–20
9	40	40	Barley	Coconut	13–22
10	40	40	Barley	0% Salt	25–39
11	40	40	0% Salt	Barley	19–24
12	40	40	Barley	Barley	1–7
13	40	40	2% Salt	Barley	40–45
14	40	40	2% Salt	Barley (new carob)	1–5
15	40	40	Barley	2% Salt	32
16	40	40	Barley	4% Salt	29
17	40	40	4% Salt	Barley	30
18	40	40	Barley	6% Salt	20
19	40	40	6% Salt	Barley	27
20	25	100	6% Salt	Barley	18
21	100	25	6% Salt	Barley	17
22	22.5	180	6% Salt	Barley	33–47
23	180	22.5	6% Salt	Barley	14
24	25	100	6% Salt	Barley	53–57
25	25	100	4% Salt	Barley	23
26	100	25	4% Salt	Barley	20
27	22.5	180	4% Salt	Barley	15–27
28	180	22.5	4% Salt	Barley	45
29	25	100	4% Salt	Barley	36
30	40	40	4% Salt	Barley	41

also assessed visually by plotting the proportion of left responses across sessions and, once statistical stability was reached, checking for any trends. If a trend appeared in the data, the condition continued until responding was visually stable, as judged by two or more research laboratory members.

The computer recorded the number of responses made on each lever, the number of reinforcers obtained on each lever, the time spent responding on each lever, the time to the first response of the session, the total postreinforcer pause time associated with each lever (from Condition 3 on), the number of changeovers, and the number of responses made during the changeover delay. In every condition these measures were recorded at the end of the session. From Condition 2, they were also recorded halfway through the session. In addition, detailed data were recorded from Condition 3 on. This included the time of every response, as well as the time of every reinforcer.

RESULTS

All analyses were carried out on the data from the last five sessions of each condition. All ratios were taken with the data from the left lever as the numerator and all logarithms were to the base 10. Five conditions were replicated (1 and 4, 5 and 12, 17 and 30, 20 and 24, 25 and 29), and analyses showed that the data in each of these pairs were generally similar. They are, however, treated as separate conditions here. Conditions 5 and 12 were similar to Conditions 1 and 4 (i.e., equal concurrent VI 40-s VI 40-s schedules) except that they involved two magazines with barley in each rather than only one magazine containing barley. The biases resulting from the different foods are analyzed first.

Bias Measures

Conditions 5 through 19 used equal concurrent VI VI schedules [i.e., $\log(r_1/r_2) = 0$], and in each pair of conditions the response alternatives associated with the foods were swapped (Table 1). From Equation 2, these pairs of conditions are described by the following equations (Davison & McCarthy, 1988):

$$\log(B_1/B_2) = \log(q_1/q_2) + \log b \quad \text{and} \quad (5)$$

$$\log(B_3/B_4) = \log(q_2/q_1) + \log b, \quad (6)$$

where B_3 and B_4 represent responses or times allocated to the left and right levers after the sides of the foods had been swapped. Subtracting Equation 6 from Equation 5 gives a measure of the relative quality of the foods:

$$0.5 \log(B_1 \cdot B_4/B_2 \cdot B_3) = \log(q_1/q_2). \quad (7)$$

The bias measures were calculated for each food using Equation 7 such that a value greater than 1.0 indicates a bias towards barley.

Figure 1 shows the logarithms of the response and time bias ratios calculated from the sum of the data from the last five sessions of each pair of conditions (calculated using Equation 7), together with their standard deviations, and the logarithms of the bias ratios based on within- and post-COD responding. These bias ratios are plotted against the food type. The data points beyond the vertical dashed lines on each graph are those from the salted barley conditions. The response and time bias measures were similar, with slightly more variability in some of the time-based measures. Little bias resulted from Coco Pops® (food number 1) versus barley. Coconut (food number 2) gave reasonably large biases towards the barley mixture. Generally, 0% salt (food number 3) and 2% salt (food number 4) gave biases close to zero. In all cases, 4% salt (food number 5) and 6% salt (food number 6) gave biases away from the salted option; however, no consistent differences appeared between the biases generated by the addition of 4% and 6% salt. The within-COD biases were all close to zero with little variability. The post-COD biases, however, were similar to the total response data, but generally larger. Coconut and 6% salt gave the largest biases.

Generalized Matching Analysis

Sensitivity. Conditions 1 through 4, 17, and 19 through 30 provide the data for three matching analyses (Table 1). The logarithms of the ratios of the numbers of responses made and of the times allocated to each alternative calculated from the sum of the last five sessions of each condition are plotted against the logarithms of the obtained reinforcer ratios in Figures 2 and 3, respectively. The dashed lines on the graphs were fitted by the method of least squares. The parameter values (a and $\log c$, Equation 1) together with measures of fit of the data to the lines are given in Table 2. The data were well described by the lines, with high percentages of variance accounted for (%VAC). All response lines showed undermatching, with no consistent changes in the slopes for the different amounts of salt. All of the time data gave steeper slopes than the response data, and some of these were greater than 1.0.

The logarithms of the ratios of the numbers of responses made within and after the COD, calculated from the sum of the data from the last five sessions of each condition, are plotted against the logarithms of the obtained reinforcer ratios in Figure 4. Lines were fitted to these data by the method of least squares, and the parameters of those lines are also presented in Table 2. The within-COD response ratios were insensitive to changes in the reinforcement-rate ratio (slopes around zero) for all three sets of conditions. The lines fitted to the post-COD response ratios are all steeper than those for the response-ratio data (Figure 2), and some overmatch. The slopes of these lines are, in fact, more like the time-allocation data (Figure 3).

Bias. The matching lines give estimates of $\log c$ (Equation 1). Comparisons show greater $\log c$ values in the 4% salt and 6% salt conditions than in the conditions with no salt (Table 2). There were no consistent differences in the biases generated by the two different salt concentrations. Comparisons of biases from pre- and post-COD responding showed no consistent differences for the conditions with no salt, but in all cases in the conditions with salt, there was more bias away from the salt in the post-COD responding than in the within-COD responding. These

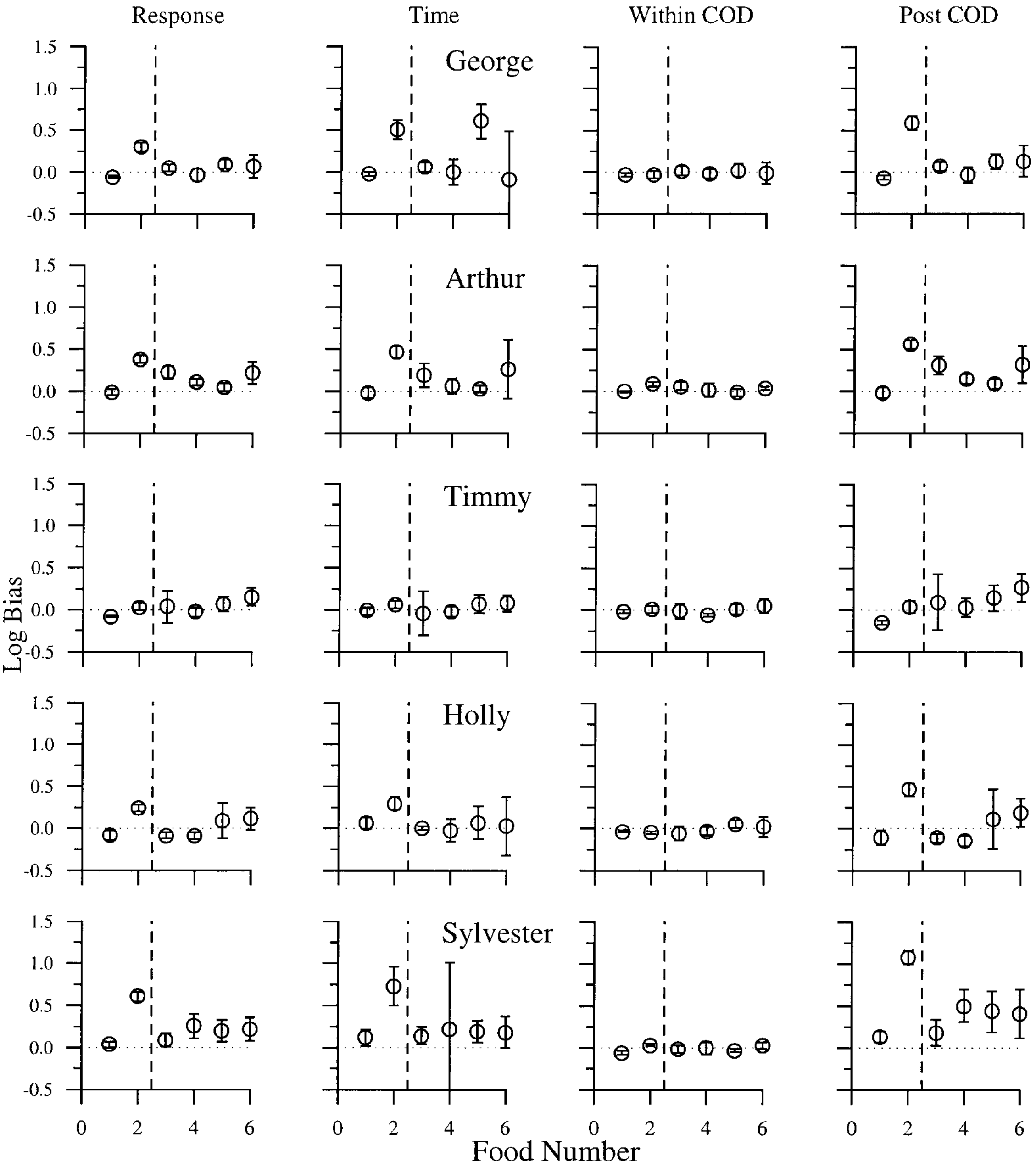

Fig. 1. The point estimates of bias [log (q_1/q_2), Equation 2] for each possum based on the response allocation, time allocation, within-COD, and post-COD response allocation for each of the six pairings of food (1 = Coco Pops®, 2 = coconut, 3 = 0% salt, 4 = 2% salt, 5 = 4% salt, and 6 = 6% salt) with the crushed barley–carob mixture and equal concurrent VI VI schedules.

measures include inherent bias and so for comparison with the point estimates of bias, inherent bias needs to be removed mathematically. This was done by using log *c* from the conditions with no salt as an estimate of inherent bias and subtracting this from log *c* for the two sets of salt conditions. Table 3 shows that for all response-based measures, the biases based on the point estimates and the biases from the matching lines are in the

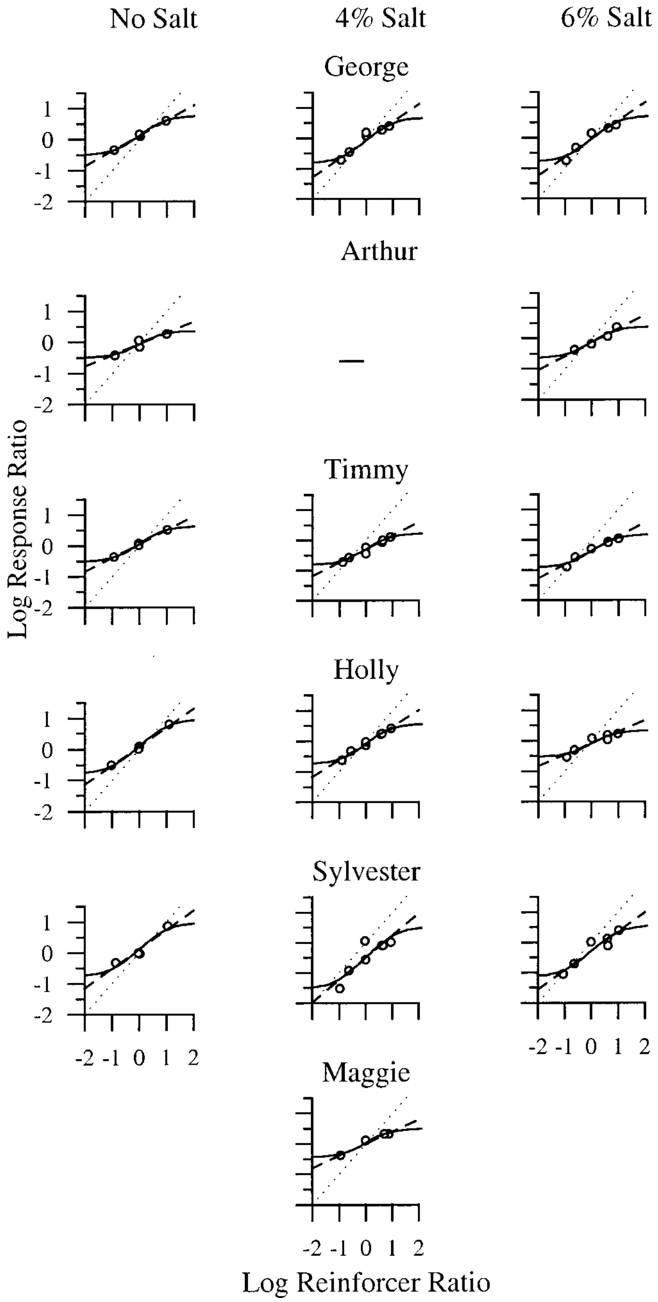

Fig. 2. The logarithms of the response ratios for the No Salt, 4% Salt, and 6% Salt conditions in which the VI schedules were varied, plotted against the logarithms of the obtained reinforcer-rate ratios for all possums. The dashed line on each graph was fitted by the method of least squares using the generalized matching law, the solid lines were fitted by nonlinear estimation using the contingency-discriminability model, and the dotted lines represent perfect matching.

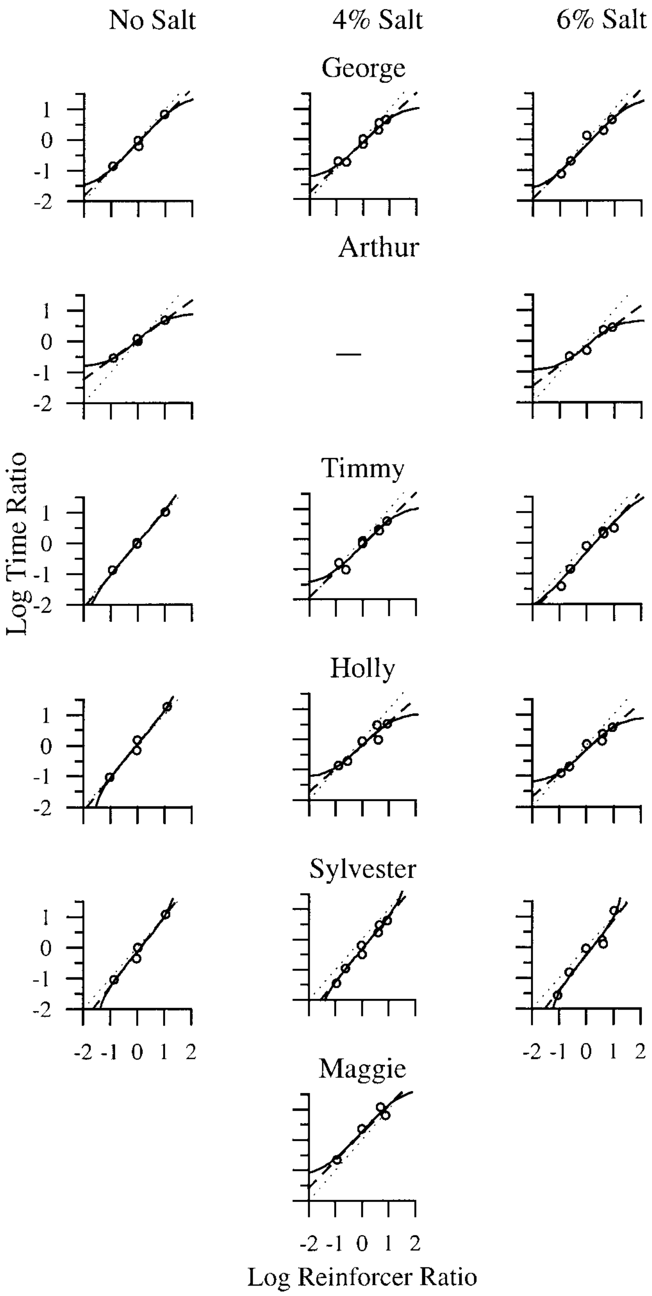

Fig. 3. The logarithms of the time-allocation ratios for the No Salt, 4% Salt, and 6% Salt conditions in which the VI schedules were varied, plotted against the logarithms of the obtained reinforcer-rate ratios for all possums. The dashed line on each graph was fitted by the method of least squares using the generalized matching law, the solid lines were fitted by nonlinear estimation using the contingency-discriminability model, and the dotted lines represent perfect matching.

Table 2

The slopes and intercepts of the lines fitted to the response, time, within-COD, and post-COD data, together with the percentage of variance accounted for by the lines (% VAC) and the standard errors of the fits (SE), for the No Salt, 4% Salt, and 6% Salt conditions separately.

	No Salt				4% Salt				6% Salt			
	a	log *c*	%VAC	SE	*a*	log *c*	%VAC	SE	*a*	log *c*	%VAC	SE
Responses												
George	0.49	0.13	99.3	0.40	0.60	−0.08	97.4	0.08	0.60	−0.04	93.5	0.13
Arthur	0.36	−0.05	90.9	0.11	—	—	—	—	0.45	−0.13	94.4	0.09
Timmy	0.45	0.07	99.3	0.04	0.45	−0.29	99.0	0.04	0.46	−0.35	96.0	0.08
Holly	0.61	0.09	99.1	0.06	0.55	−0.08	98.6	0.05	0.38	−0.08	88.1	0.12
Sylvester	0.63	0.10	93.4	0.16	0.74	−0.50	78.5	0.33	0.64	−0.28	89.4	0.20
Maggie	—	—	—	—	0.40	0.00	99.1	0.05	—	—	—	—
Mean	0.51	0.07	96.4	0.15	0.55	−0.19	94.5	0.11	0.51	−0.18	92.2	0.12
Time												
George	0.88	−0.08	98.1	0.12	0.82	−0.11	96.1	0.14	0.89	−0.16	95.6	0.16
Arthur	0.64	0.05	99.6	0.04	—	—	—	—	0.65	−0.15	93.2	0.15
Timmy	1.06	0.02	99.6	0.06	0.86	−0.21	94.3	0.17	0.98	−0.30	95.6	0.18
Holly	1.09	0.04	98.0	0.16	0.77	−0.20	91.5	0.19	0.76	−0.16	95.9	0.13
Sylvester	1.13	−0.14	97.3	0.18	1.07	−0.32	98.3	0.12	1.13	−0.26	93.1	0.28
Maggie	—	—	—	—	0.90	0.22	93.9	0.33	—	—	—	—
Mean	0.96	−0.02	98.5	0.11	0.88	−0.12	94.8	0.19	0.88	−0.21	94.7	0.18
Within-COD												
George	0.09	0.44	62.3	0.07	0.05	0.19	13.7	0.10	0.06	0.26	66.9	0.03
Arthur	0.05	−0.12	7.3	0.16	—	—	—	—	−0.01	0.11	5.4	0.03
Timmy	−0.11	−0.03	73.0	0.06	0.00	−0.21	1.0	0.30	0.02	−0.22	4.6	0.09
Holly	0.15	0.18	28.8	0.25	−0.06	0.05	28.3	0.08	−0.02	0.20	6.0	0.05
Sylvester	0.04	0.28	4.3	0.19	−0.06	−0.02	5.2	0.22	0.09	0.21	25.7	0.14
Maggie	—	—	—	—	−0.02	0.12	22.7	0.04	—	—	—	—
Mean	0.04	0.15	35.1	0.15	−0.02	0.03	14.2	0.15	0.03	−0.11	21.7	0.07
Post-COD												
George	0.76	−0.09	98.8	0.08	0.82	−0.19	99.1	0.07	0.89	−0.20	95.8	0.16
Arthur	0.49	−0.02	92.8	0.13	—	—	—	—	0.65	−0.24	94.1	0.14
Timmy	0.78	0.07	98.4	0.10	0.74	−0.34	99.7	0.03	0.87	−0.50	97.0	0.13
Holly	0.79	−0.02	98.7	0.10	0.90	−0.16	98.2	0.10	0.61	−0.20	93.2	0.14
Sylvester	1.01	−0.09	98.5	0.12	1.08	−0.72	92.5	0.26	1.05	−0.69	94.3	0.23
Maggie	—	—	—	—	0.79	−0.01	96.9	0.20	—	—	—	—
Mean	0.77	−0.03	97.4	0.11	0.87	−0.28	97.3	0.13	0.81	−0.37	94.9	0.16

same direction—towards the barley. In all cases, the 6% salt gave bigger biases although the absolute values of the matching-line biases are larger than the point estimates. The time biases were more variable than the response biases and were generally in the same direction, but the point estimates and the matching-line estimates were not systematically different.

Contingency-Discriminability Analysis

Discriminability. Using non-linear regression analysis, the logarithmic version of Equation 4 was fitted to the data previously used in the generalized matching law analysis. The solid lines presented in Figures 2, 3, and 4 for all but the within-COD data show these functions. The resulting parameter values (d_r and log c_{cd}) for all data are given in Table 4 along with the %VAC by each function. Both the time and response data were well described by the functions. Likewise, most of the within- and post-COD data are well described by these functions. Where the fitted functions curve upwards at the right of the graph, however, the values of d_r (Table 4) are negative and are associated with a values greater than 1.0. In all other cases, comparisons with a from the generalized matching law analysis (Table 2) show d_r changes, as predicted, with changes in a.

Bias (log c_{cd}). Comparison of the data in Ta-

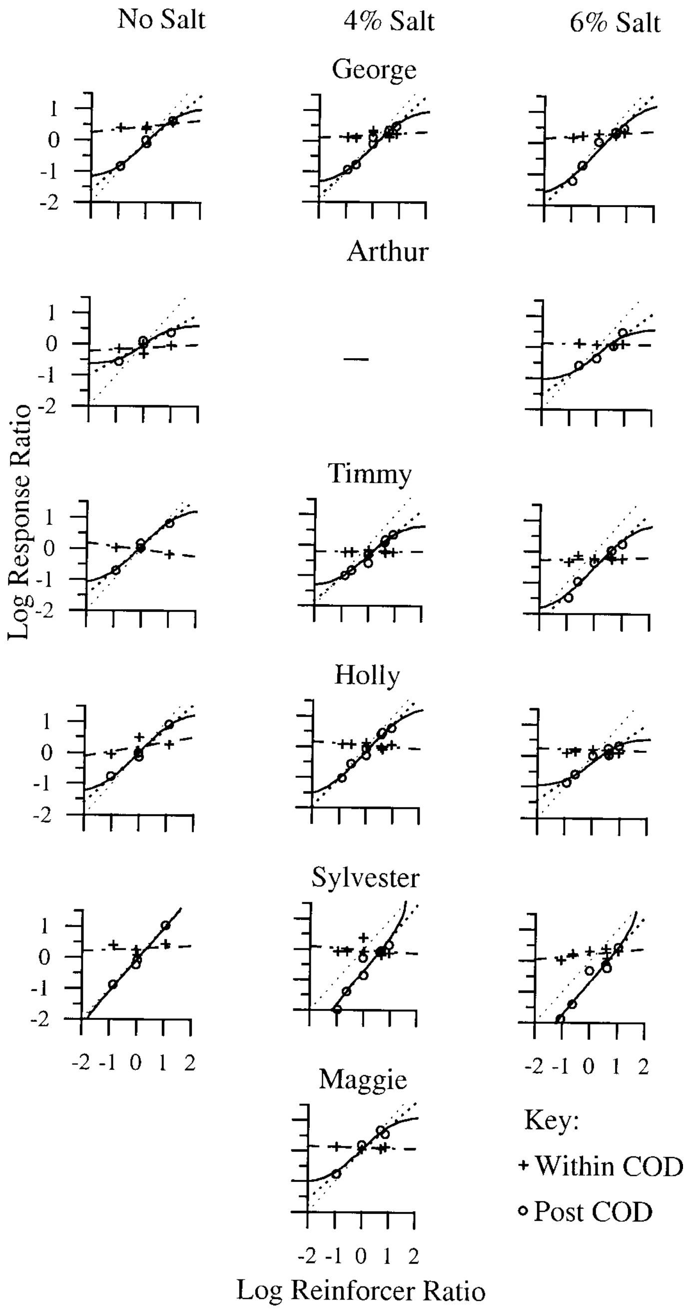

Fig. 4. The logarithms of the within-COD (pluses) and post-COD (circles) response ratios for the No Salt, 4% Salt, and 6% Salt conditions in which the VI schedules were varied, plotted against the logarithms of the obtained reinforcer-rate ratios for all possums. The dashed and dark dotted lines on each graph were fitted by the method of least squares, the solid lines were fitted by nonlinear estimation, and the light dotted lines represent perfect matching.

Table 3

The estimates of bias (log q1/q2, Equation 2) based on the equal schedule conditions (point estimates) and derived from the GML fits for the 4% and 6% Salt conditions.

	Responses		Time		Within-COD		Post-COD	
	4%	6%	4%	6%	4%	6%	4%	6%
Point Estimate								
George	−0.09	−0.07	−0.61	0.09	−0.02	0.01	−0.13	−0.13
Timmy	−0.07	−0.15	−0.07	−0.08	−0.01	−0.05	−0.15	−0.27
Holly	−0.09	−0.12	−0.06	−0.03	−0.05	−0.02	−0.11	−0.19
Sylvester	−0.20	−0.22	−0.19	−0.18	0.03	−0.03	−0.44	−0.41
Mean	−0.10	−0.16	−0.25	−0.11	−0.01	−0.03	−0.21	−0.28
Matching Line Estimate								
George	−0.21	−0.17	−0.03	−0.08	−0.25	−0.18	−0.10	−0.11
Timmy	−0.36	−0.42	−0.23	−0.32	−0.18	−0.19	−0.41	−0.57
Holly	−0.17	−0.17	−0.24	−0.20	−0.13	−0.06	−0.14	−0.18
Sylvester	−0.60	−0.38	−0.18	−0.12	−0.30	−0.07	−0.63	−0.60
Mean	−0.26	−0.25	−0.10	−0.18	−0.13	−0.05	−0.25	−0.34

bles 2 and 4 shows that the biases generated by the contingency-discriminability model were almost exactly mathematically equal (differences range between 0.12 and −0.01) to those generated by the generalized matching law analysis and changed in the same way.

DISCUSSION

The generalized matching law fitted and described the matching data well. The possums' response–allocation measures undermatched, and time spent responding came closer to matching changes in reinforcer rate. In this, the data are relatively similar to many other species. These possums' responding, however, generally undermatched more than expected for species such as pigeons (Baum, 1979; Taylor & Davison, 1983). In this way, they may be more similar to goats and cows (e.g., Foster et al., 1996; Foster et al., 1997; Matthews & Temple, 1979). There is no clear reason for this finding. Various variables may have contributed to this undermatching such as discriminability of the source of reinforcement (Davison & Jenkins, 1985) and the COD length (Temple et al., 1995). Two separate magazines might be expected to improve discriminability of the source of reinforcement, but this did not decrease the degree of undermatching. The COD length was not varied here, and this requires further study with this species.

When the response data were separated into responding during and after the COD, and both were plotted against relative reinforcer rate, most of the changes with reinforcer rate were post-COD rather than during the COD. In this, the possums' data are similar to those reported for other species (e.g., McAdie et al., 1996; Temple et al., 1995).

It was also possible to analyze responding under equal schedules with differing foods in terms of within- and post-COD responding. By analogy with the reinforcer-rate changes, it might be expected that responding during the COD would show little bias, and any food biases would occur in post-COD responding. Figure 1 shows that this was so, and the result is comparable to that of McAdie (1991) who found, using hens as subjects, that most bias in responding arising from the presence of overlaid sounds occurred after the COD. Several authors (Baum, 1982; McAdie et al., 1996; Temple et al., 1995) have argued that such findings suggest that if only post-COD data show changes, then these should be the only data considered when measuring such preferences.

Given the similarity of the present findings to those found when other species respond on concurrent schedules of reinforcement, it appears reasonable to assume that the results of the present analyses carried out to test the utility of the generalized matching law and contingency-discriminability model will be generalizable to other species, rather than being specific to possums per se. This analysis showed that the contingency-discriminability model also fitted the data well in terms of the

Table 4

The parameters resulting from the fit of the contingency-discriminability model (Equation 3) to the No Salt, 4% Salt, and 6% Salt data, together with the %VAC by the fits, for the response, time, within-COD, and post-COD data.

	No Salt			4% Salt			6% Salt		
	d_r	log c_{cd}	%VAC	d_r	log c_{cd}	%VAC	d_r	log c_{cd}	%VAC
Responses									
George	4.25	0.13	99.3	5.56	−0.08	96.9	5.62	−0.04	92.3
Arthur	2.75	−0.05	91.1	—	—	—	3.26	−0.12	91.1
Timmy	3.78	0.07	99.2	3.30	−0.29	98.3	3.51	−0.36	95.1
Holly	7.20	0.09	98.9	4.55	−0.08	97.8	2.71	−0.09	86.7
Sylvester	7.05	0.11	92.3	10.65	−0.50	77.7	7.05	−0.29	87.7
Maggie	—	—	—	2.93	0.03	96.0	—	—	—
Mean	5.01	0.07	96.2	5.40	−0.18	93.3	4.43	−0.18	90.6
Time									
George	30.05	−0.08	98.0	15.19	−0.11	96.7	33.09	−0.17	95.3
Arthur	7.36	0.05	99.6	—	—	—	6.66	−0.14	93.7
Timmy	−68.63	0.02	99.7	19.16	−0.21	94.7	115.37	−0.30	95.7
Holly	−60.17	0.03	98.0	11.35	−0.20	91.6	11.71	−0.16	95.6
Sylvester	−36.37	−0.15	97.4	−54.12	−0.20	98.4	−14.54	−0.26	95.0
Maggie	—	—	—	27.82	0.26	93.2	—	—	—
Mean	−25.55	−0.03	98.5	3.88	−0.09	94.9	30.46	−0.21	95.0
Within-COD									
George	1.30	0.44	61.2	1.23	0.18	15.0	1.15	0.26	62.4
Arthur	1.14	−0.12	6.9	—	—	—	0.98	0.11	8.0
Timmy	0.74	−0.03	71.3	1.01	−0.21	1.0	1.05	−0.22	3.1
Holly	1.57	0.18	29.5	0.96	0.06	66.2	0.95	0.12	7.6
Sylvester	1.10	0.28	3.1	−0.49	−0.01	8.2	1.20	0.19	24.4
Maggie	—	—	—	0.96	0.12	25.6	—	—	—
Mean	1.17	0.15	34.4	0.73	0.03	23.2	1.07	0.09	21.1
Post-COD									
George	12.41	−0.09	98.8	16.01	−0.19	99.3	30.47	−0.20	95.6
Arthur	4.22	−0.02	93.5	—	—	—	6.61	−0.23	91.8
Timmy	15.56	0.07	98.5	10.13	−0.34	99.7	25.35	−0.50	96.9
Holly	17.26	−0.01	98.5	29.68	−0.16	98.3	5.87	−0.21	92.9
Sylvester	−220.94	−0.09	98.5	−46.69	−0.72	92.6	−64.38	−0.69	94.5
Maggie	—	—	—	12.32	0.04	94.5	—	—	—
Mean	−34.30	−0.03	97.6	4.29	−0.27	96.9	0.78	−0.37	94.3

percentage of variance accounted for. The negative d_r values found for the contingency-discriminability model, however, make no intuitive sense. In an attempt to remove these anomalies, the model was fitted again with the additional parameter, *w,* included (Equation 4). The new parameter values are shown in Table 5. The addition of *w* did not help, as there was no consistent improvement to the negative d_r's. While some d_r's became positive, others became negative. The parameter *w* is described as being the reinforcers lost per minute due to changing over, and it was sometimes large and sometimes both large and negative. These values remain uninterpretable.

Within the contingency-discriminability model, d_r is said to reflect the discriminability of the sources of reinforcement. One possibility was that having different flavored feeds coming from separate magazines would have made this discrimination easier, and therefore increased d_r. The values of d_r did not increase systematically over the changes between 0, 4, and 6% salt, and hence this suggestion was not supported. Bias measures were consistent and did not vary systematically with reinforcer rate, and both models gave almost identical bias measures.

Davison and Jones (1995) reported that the contingency-discriminability model provided a better fit than the generalized matching law for their data. They argued that when data are collected over the usual range of re-

Table 5

The parameters resulting from the fit of the punishment version of the contingency-discriminability model (Equation 4) to the post-COD data from the No Salt, 4% Salt, and 6% Salt data, together with the %VAC by the fits.

	d_r	$\log c_{cd}$	w	%VAC
No Salt				
George	−1.00	−0.08	−1936254.17	99.0
Arthur	4.22	−0.02	0.00	93.5
Timmy	−8.16	0.11	−65.72	99.0
Holly	1.77	−0.07	73.91	99.4
Sylvester	4.01	−0.16	56.89	99.7
Mean	0.17	−0.04	−387237.82	98.1
4% Salt				
George	18.33	−0.19	−2.35	99.3
Timmy	3.57	−0.33	30.46	99.8
Holly	8.68	−0.16	15.30	98.6
Sylvester	2.45	−0.50	68.80	97.3
Maggie	3.50	−0.01	35.20	100.0
Mean	7.31	−0.24	29.48	99.0
6% Salt				
George	−5.73	−0.19	−83.73	96.6
Arthur	1.86	−0.27	80.26	99.2
Timmy	3.25	−0.49	52.30	97.4
Holly	2.01	−0.18	59.79	95.5
Sylvester	837.05	−0.69	2.54	94.5
Mean	167.69	−0.36	22.23	96.6

inforcer-rate ratios, 0.1:1.0 to 10:1.0 (Davison & Jenkins, 1985), as was done here, the two models differ little in their descriptions of behavior. Because, however, the contingency-discriminability model predicts an s-shaped function, while the generalized matching law predicts a straight line, if the contingency-discriminability model is more appropriate, behavior at extreme reinforcer-rate ratios should deviate more from perfect matching than behavior at reinforcer-rate ratios within the range normally used. Davison and Jones presented pigeons with nine concurrent VI VI schedule pairs. Five of those pairs had reinforcer-rate ratios within the range normally used (providing the central data), while the remaining four pairs gave more extreme reinforcer-rate ratios. Using the generalized matching law, Davison and Jones analyzed the response-allocation data from all nine schedule pairs, and also the central pairs alone. They found that the estimates of a were greater when only the central data were analyzed. In other words, behavior at the extreme reinforcer-rate ratios was less sensitive to reinforcer-rate differences. They then analyzed the data from all nine schedule pairs using the contingency-discriminability model. Both models provided good fits to the data from all schedule pairs, although Davison and Jones suggested that the contingency-discriminability model appeared preferable because it accounted for the deviations from the straight line predicted by the generalized matching law. Based on the above analyses they suggested that the contingency-discriminability model was more appropriate for the analysis of choice.

They did not test whether the response measures at extreme reinforcer-rate ratios were well predicted by the contingency-discriminability model when only the central data were analyzed. They stated that this analysis was not done because the parameters of the contingency-discriminability model are determined mainly by the extreme data. If, however, the contingency-discriminability model predicts that choice becomes less extreme as the reinforcer-rate ratio becomes more extreme, analyses using the central data should resemble those using all of the data.

Using Davison and Jones's (1985) data, both the generalized matching law and the contingency-discriminability model were fitted to the five central data points, all nine data points, and the four extreme data points. Figure 5 shows the difference between the predicted and the obtained response ratios (i.e., the logarithms of the response ratios predicted by the generalized matching law minus the logarithms of the obtained response ratios) plotted against the logarithms of the obtained reinforcer ratios for all data points. In the left panel, all data were used in obtaining the a and $\log c$ values used to make the predictions, in the center panel only the five central data points were used, and in the right panel only the four extreme data points were used. The same analyses carried out with the contingency-discriminability model are presented in Figure 6. The solid horizontal line on each of the graphs in these figures represents the point where the predicted and obtained values are equal. Therefore, the closer the data points are to this line, the better the model predicts the subjects' actual behavior. It can be seen from these figures that when all of the data were used, and when only the extreme data were used, both models predicted the subjects' behavior well. There was, in fact, little differ-

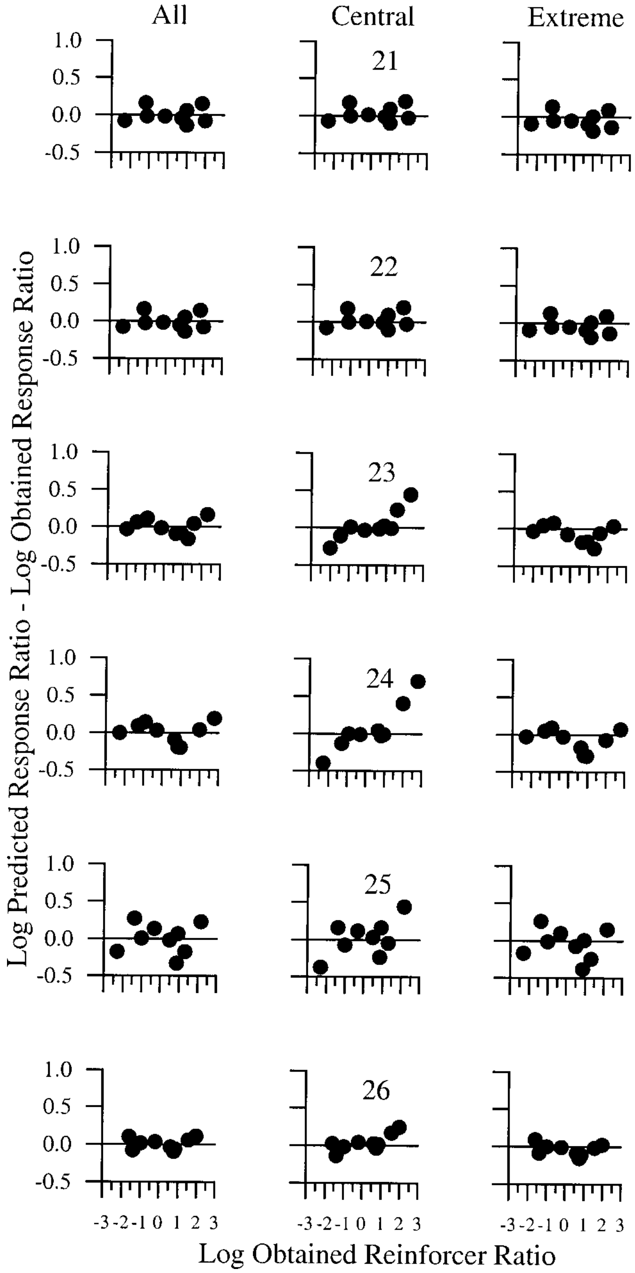

Fig. 5. The difference between the response ratios predicted by the generalized matching law and those obtained by Davison and Jones (1995). The predictions used in the left panel were based on all their data, those used for the center panel excluded the data obtained with extreme reinforcer ratios, and those in the right panel were based on only the extreme reinforcer ratios. The horizontal lines show perfect prediction.

ence between how well the two models predicted behavior. When the generalized matching law was fitted to the central data, the equation did not predict choice at extreme reinforcer-rate ratios well because the observed response-allocation ratios were less extreme than predicted. When the same analysis was conducted using the contingency-discriminability model, the observed response-allocation ratios were more extreme than

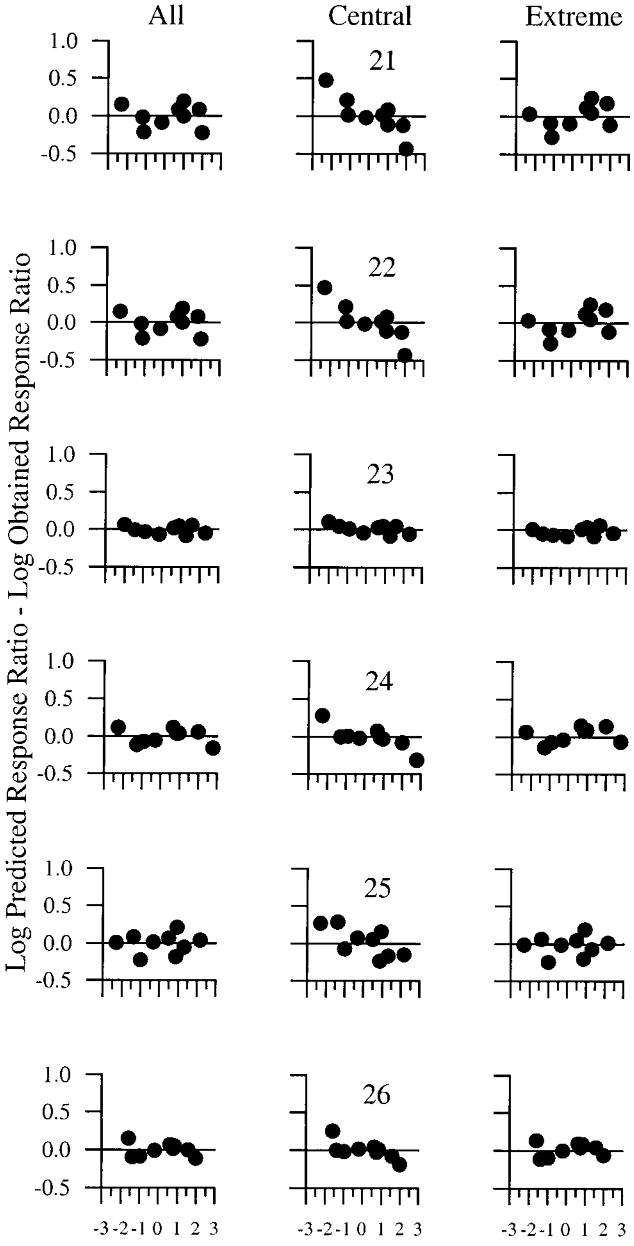

Fig. 6. The difference between the response ratios predicted by the contingency-discriminability model and those obtained by Davison and Jones (1995). The predictions used in the left panel were based on all their data, those used for the center panel excluded the data obtained with extreme reinforcer ratios, and those in the right panel were based on only the extreme reinforcer ratios. The horizontal lines show perfect prediction.

predicted. Overall, then, neither model appeared better than the other at predicting behavior in any of the above cases, although both models predict more accurately when a wider range of reinforcer-rate ratios is used. Thus, even including more extreme reinforcer-rate ratios does not appear to help in deciding which model is more appropriate.

Baum et al. (1999) suggested that the s-shaped functions found by Davison and Jones

(1995) may have resulted from aspects of their experimental procedure, such as the use of a changeover-key procedure, confusable stimuli (i.e., two different levels of brightness), dependent scheduling, and a 3-s COD. To test this suggestion, Baum et al. studied pigeons' choice behavior over a wide range of reinforcer-rate ratios using independent schedules and a standard two-key concurrent schedule procedure without a COD. In later conditions, involving extreme reinforcer-rate ratios, they changed to dependent scheduling and studied choice behavior both with and without a 3-s COD. Baum et al. failed to obtain the s-shaped functions obtained by Davison and Jones when the data from the former conditions were used and when the data points from the latter conditions were included in the analyses. In fact, in both cases they found that the generalized matching law provided a better description of their subjects' behavior than the contingency-discriminability model when the %VAC measures were compared. On the basis of their findings, Baum et al. argued that Davison and Jones's results arose from the use of confusable stimuli.

Baum et al. (1999) went on to suggest that the small amount of undermatching typically found in studies on concurrent VI VI schedule performance is a direct result of the way the data are analyzed. They suggested that instead of examining behavior in terms of the position or color of the response alternatives, it might be more appropriate to look at behavior in terms of the preferred and nonpreferred alternatives. When their data were treated in this way, the undermatching that was observed with the traditional generalized matching law appeared as a bias towards the nonpreferred alternative (with a slope of approximately 1.0). As a result of this finding, they proposed that there are two distinct reasons why undermatching is often observed. The first, which they argued was the case in their experiment, results from fitting an inappropriate equation (i.e., the traditional generalized matching law) to the data. The second results from the use of poorly discriminable alternatives, and, in such cases, Baum et al. argue that the contingency-discriminability model (also expressed as the ratios of preferred to nonpreferred alternatives) should be used instead. Baum et al. did note, however, that such analyses are only possible when no apparent position biases are observed. Although, in the present study, the position biases obtained during the conditions where the same food was associated with both alternatives were small, there were too few data points obtained from those conditions to make the analyses possible. The presence of position biases in the remaining data also prevents such analyses.

In conclusion, then, both the generalized matching law and the contingency-discriminability model gave good descriptions of the present data sets, but given the strange values of some parameters found in the contingency-discriminability model, any argument for this model based on the interpretability of the parameter values becomes weak. It may well be worthwhile retaining the generalized matching law, at least as a descriptor of such data, and particularly when position biases are present.

REFERENCES

Alsop, B., & Davison, M. (1991). Effects of varying stimulus disparity and the reinforcer ratio in concurrent-schedule and signal-detection procedures. *Journal of the Experimental Analysis of Behavior, 56,* 67–80.

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior, 22,* 231–242.

Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior, 32,* 269–281.

Baum, W. M. (1982). Choice, changeover, and travel. *Journal of the Experimental Analysis of Behavior, 38,* 35–49.

Baum, W. M., Schwendiman, J. W., & Bell, K. E. (1999). Choice, contingency discrimination and foraging theory. *Journal of the Experimental Analysis of Behavior, 71,* 355–373.

Chung, S., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior, 10,* 67–74.

Clout, M. N., & Sarre, S. D. (1997). Model marsupial or menace? A review of research on brushtail possums in Australia and New Zealand. *Wildlife Society Bulletin, 25,* 168–172.

Davison, M. C., & Hunter, I. W. (1976). Performance on variable-interval schedules arranged singly and concurrently. *Journal of the Experimental Analysis of Behavior, 25,* 335–345.

Davison, M., & Jenkins, P. E. (1985). Stimulus discriminability, contingency discriminability, and schedule performance. *Animal Learning & Behavior, 13,* 77–84.

Davison, M., & Jones, B. M. (1995). A quantitative analysis of extreme choice. *Journal of the Experimental Analysis of Behavior, 64,* 147–162.

Davison, M., & Jones, B. M. (1998). Performance on concurrent variable-interval extinction schedules. *Journal of the Experimental Analysis of Behavior, 69,* 49–57.

Davison, M. C., & McCarthy, D. (1988). *The matching law: A research review.* Hillsdale NJ: Erlbaum.

Davison, M., & McCarthy, D. (1994). Effects of the discriminability of alternatives in three alternative concurrent-schedule performance. *Journal of the Experimental Analysis of Behavior, 61,* 45–63.

de Villiers, P. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233–287). Englewood Cliffs, NJ: Prentice-Hall.

de Villiers, P. A. (1980). Toward a quantitative theory of punishment. *Journal of the Experimental Analysis of Behavior, 33,* 15–25.

Dougherty, D. M., & Lewis, P. (1992). Matching by horses on several concurrent variable-interval schedules. *Behavioral Processes, 26,* 69–76.

Farley, J. (1980). Reinforcement and punishment effects in concurrent schedules: A test of two models. *Journal of the Experimental Analysis of Behavior, 33,* 311–326.

Foster, T. M., Matthews, L. R., Temple, W., & Poling, A. (1997). Concurrent schedule performance in domestic goats: Persistent undermatching. *Behavioral Processes, 40,* 231–237.

Foster, T. M., Temple, W., Robertson, B., Nair, V., & Poling, A. (1996). Concurrent schedule performance in dairy cows: Persistent undermatching. *Journal of the Experimental Analysis of Behavior, 65,* 57–80.

Hollard, V., & Davison, M. C. (1971). Preference for qualitatively different reinforcers. *Journal of the Experimental Analysis of Behavior, 16,* 375–380.

Hudson, D., Foster, T. M., & Temple, W. (1999). Fixed-ratio schedule performance of possum (*Trichosurus vulpecula*). *New Zealand Journal of Psychology, 28,* 80–86.

Jones, B. M., & Davison, M. (1998). Reporting contingencies of reinforcement in concurrent schedules. *Journal of the Experimental Analysis of Behavior, 69,* 161–183.

Mace, F. C., Neef, N. A., Shade, D., & Mauro, B. C. (1994). Limited matching on concurrent-schedule reinforcement of academic behavior. *Journal of Applied Behavior Analysis, 27,* 585–596.

Matthews, L. R., & Temple, W. (1979). Concurrent schedule assessment of food preference in cows. *Journal of the Experimental Analysis of Behavior, 32,* 245–254.

McAdie, T. M. (1991). *Noise as a biaser of concurrent schedule performance.* Unpublished master's thesis, University of Waikato, Hamilton, New Zealand.

McAdie, T. M., Foster, T. M., & Temple, W. (1996). Concurrent schedules: Quantifying the aversiveness of noise. *Journal of the Experimental Analysis of Behavior, 65,* 37–55.

Miller, H. L. (1976). Matching based hedonic scaling in the pigeon. *Journal of the Experimental Analysis of Behavior, 26,* 335–347.

Miller, J. T., Saunders, S. S., & Bourland, G. (1980). The role of stimulus disparity in concurrently available reinforcement schedules. *Animal Learning & Behavior, 8,* 635–641.

Muir, K. M. (1997). *Multiple-concurrent schedule performance of the New Zealand brushtail possum.* Unpublished master's thesis, University of Waikato, Hamilton, New Zealand.

Shull, R. L., & Pliskoff, S. S. (1967). Changeover delay and concurrent schedules: Some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior, 10,* 517–527.

Signal, T. D., Foster, T. M., & Temple, W. (2001). Determination of auditory thresholds in the brushtail possum (*Trichosurus vulpecula*). *Physiology & Behavior, 23,* 195–200.

Signal, T. D., Temple, W., & Foster, T. M. (2001). Visual discrimination in the brushtail possum (*Trichosurus vulpecula*). *Australian Journal of Psychology, 53,* 152–154.

Stubbs, D. A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior, 12,* 887–895.

Sumpter, C. E., Foster, T. M., & Temple, W. (1995). Predicting and scaling hens' preferences for topographically different responses. *Journal of the Experimental Analysis of Behavior, 63,* 71–95.

Sumpter, C. E., Temple, W., & Foster, T. M. (1998). Response form, force, and number: Effects on concurrent schedule performance. *Journal of the Experimental Analysis of Behavior, 70,* 45–68.

Taylor, R., & Davison, M. C. (1983). Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior, 39,* 191–198.

Temple, W., Scown, J. M., & Foster, T. M. (1995). Changeover delay and concurrent-schedule performance in domestic hens. *Journal of the Experimental Analysis of Behavior, 63,* 71–95.

Todorov, J. C. (1973). Interaction of frequency and magnitude of reinforcement on concurrent performances. *Journal of the Experimental Analysis of Behavior, 19,* 451–458.

Wearden, J. H., & Burgess, I. S. (1982). Matching since Baum (1979). *Journal of the Experimental Analysis of Behavior, 38,* 339–348.

Williams, B. A. (1988). Reinforcement, choice, and response strength. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology: Vol 2. Learning and cognition* (pp. 167–244). New York: Wiley.

Wynne, C. D. L., & McLean, I. G. (1999). The comparative psychology of marsupials. *Australian Journal of Psychology, 51,* 111–116.

Received August 7, 2001
Final acceptance December 30, 2002