PREDICTING AND SCALING HENS' PREFERENCES FOR TOPOGRAPHICALLY DIFFERENT RESPONSES

CATHERINE E. SUMPTER, T. MARY FOSTER, AND WILLIAM TEMPLE

UNIVERSITY OF WAIKATO, NEW ZEALAND

Six hens were exposed to several concurrent (second-order) variable-interval schedules in which the response requirements on the alternatives were varied. The response requirements were one key peck versus five key pecks, one key peck versus one door push, and five key pecks versus one door push. Response- and time-allocation ratios undermatched the obtained reinforcement ratios but were well described by the generalized matching law. Time and response bias estimates from two pairs of response requirements were used to predict bias in the third pairing. The predicted values were close to those obtained; this result supports the notion that both numerically and topographically different responses act as constant sources of bias within the generalized matching law. The differences between the response and time biases could be accounted for by the different times needed to complete each response requirement. The results also suggest that the door push is a useful operant for research with domestic hens.

Key words: concurrent schedules, second-order schedules, different responses, matching law, key pecks, door pushes, hens

Performance under concurrent schedules of reinforcement is well described by the generalized matching law (Baum, 1979):

$$\frac{B_1}{B_2} = c \left(\frac{r_1}{r_2} \right)^a, \quad (1)$$

where B refers to the behavioral measure (responses emitted or time allocated), r refers to the reinforcers obtained, and the subscripts denote two alternatives. The exponent a , termed *sensitivity to reinforcement* (Baum, 1979), measures the rate at which the response or time ratios change with changes in reinforcement ratios. The parameter c , termed *bias* (Baum, 1974), measures the constant preference for one response over the other that might be attributable to the equipment or inherent in the subject. Killeen (1972) suggested that c may be a composite of several factors that combine multiplicatively to determine choice.

Several researchers (Hollard & Davison, 1971; Matthews & Temple, 1979; Miller, 1976) have examined the quantitative effects of different types of reinforcers on bias (c in Equation 1). Matthews and Temple, for example, measured preference for hay and dairy meal in cows over five variations of reinforce-

ment-rate ratios. Food quality was found to function as a constant contribution to c .

Miller (1976) used the generalized matching law to scale animals' preferences for different reinforcers. In a concurrent-schedule procedure, pigeons were given a choice between two different types of grains. Later, one of the grains was replaced by a third kind. The biases obtained for Grain A over Grain B and for Grain A over Grain C were then used to estimate the relative preference values for the two grains not previously paired. Predictions based on these estimates were compared to the data obtained when the subjects chose between the third pairing of grains. The predictions were not numerically precise, but were in the right direction. Thus, it is possible to scale and predict (at least ordinal) preferences for different types of reinforcers.

Animals often allocate their behavior across different responses; for example, birds both scratch and peck to obtain food. However, most research on matching has varied parameters of reinforcement (e.g., reinforcement rate, amount, immediacy, and quality; see Davison & McCarthy, 1988), and, typically, the same response has been used on the alternatives. There has been little research on the effects of variations in the response on matching.

Beautrais and Davison (1977) measured performance under concurrent second-order schedules of reinforcement, whereby the behavior specified by a schedule of reinforcement is defined as the first-order operant and is itself

Address correspondence and reprint requests to Catherine E. Sumpter, Psychology Department, University of Waikato, Private Bag 3105, Hamilton, New Zealand.

reinforced according to another schedule (Kelleher, 1966). Thus, in their experiment, the responses were not topographically different, but consisted of fixed-ratio (FR) requirements reinforced on variable-interval (VI) schedules. Both the FR requirements and the reinforcement-rate ratios were varied across experimental conditions. In general, their data show that changes in first-order operants result in orderly shifts in bias away from the larger response requirement.

A few studies have examined the effects of topographically different responses on performance under concurrent schedules (Davison & Ferguson, 1978; Hanson & Green, 1986; McSweeney, 1978; Wheatley & Engberg, 1978). In each of these, the relation between one key peck and one treadle press was examined over a range of reinforcement rates. With the exception of McSweeney's data, performance was biased towards the key-peck requirement, particularly when measured in terms of response rather than time allocation.

No previous study has investigated all possible combinations of three responses, either as different second-order schedules or as different response types. If changes in response form or response parameters (such as second-order requirements) result in constant bias, then the generalized matching law can be used to scale response requirements (cf. Miller, 1976). These scaled values would predict the readiness with which a particular response will be executed, independently of reinforcement rate, amount, immediacy, and type. In a fashion similar to Miller's prediction of untested food preferences, two bias measures using two different and one common response type could predict the bias expected using the untested pair. One benefit of being able to scale responses is that it may lead to the identification of the factors that give rise to bias—factors such as the effort or time needed to emit the response.

As a result of European and Australasian interest in layer hen welfare (e.g., Dawkins, 1990), this laboratory is researching the preferences of domestic hens. Domestic hens are descended from the Burmese red junglefowl (*Gallus gallus spadiceus*), which is thought to be the wild form (Wood-Gush, 1971). In the natural environment, junglefowl allocate much of their time to activities such as scratching in leaf litter and pushing through undergrowth

to reach nest sites (Collias, Collias, Hunsaker, & Minning, 1966; Dawkins, 1989). In a laboratory analogue of this behavior, hens have been required to push through "doors" to gain access to food and nest boxes (Duncan & Kite, 1987; Petherick & Rutter, 1990). "Door pushing" is clearly a potential operant for use in the assessment of hens' preferences, particularly for commodities other than food. It is topographically a vastly different response from key pecking and may, or may not, act similarly. There are, however, no data comparing hens' (or other birds') response patterns on door-pushing and key-pecking operants.

The purpose of the present experiment was to discover if different responses by hens under concurrent schedules act as constant sources of bias within the generalized matching law. Specifically, it was intended to establish equivalent measures of the biasing effects of a response unit of five key pecks and a response unit of one door push when each were paired with a single key-peck response. On the basis of these measures, the biasing effects of a door-push requirement versus a requirement of five key pecks were to be predicted. These predictions were then to be compared to the biases obtained when the door push and FR 5 requirements were paired.

METHOD

Subjects

Six Shaver Starcross hens, numbered 61 to 66, were maintained at 80% ($\pm 5\%$) of their free-feeding body weights through daily weighing and the provision of supplementary feed (commercial laying pellets). They were housed in individual cages (30 cm by 45 cm by 43 cm) with water freely available. Grit and vitamins were supplied weekly. The birds were approximately 12 months old at the beginning of the experiment. All birds had experience with pecking a single key for food reinforcement, but not with concurrently available keys or with the door-push response.

Apparatus

A particleboard experimental chamber (inside dimensions 57 cm long, 42 cm wide, and 54 cm high) was used. The floor was a thick metal grid enclosed in an open steel tray, 3.5 cm high. A fan in the rear wall of the chamber provided air circulation and masking noise. A

Fig. 1. Schematic diagram of the experimental chamber modified to include the door response unit. The parts of the door indicated are the microswitch (1), the metal arm that contacts the microswitch (2), the brass rods through which the hens push their necks and heads (3), and the metal pins on which weights may be placed (4). The attached box (5), the position of the door light (6), the position of the left key (7), and the hole for access to the magazine (8) are also shown.

hole (7 cm by 10 cm), centered on the front wall 8.5 cm above the grid floor, allowed access to the food magazine. At the rear of the magazine was a 1-W white bulb that illuminated the food when the hopper was raised. The magazine light and the response manipulanda lights were the only sources of illumination in the chamber. Solid-state logic-control equipment, located in an adjoining room, controlled all experimental events. Data were recorded on digital counters and in a data book.

Part 1. During Part 1, the chamber contained two response keys, each 3 cm in diameter, situated on the front wall 17 cm apart and 36 cm above the floor. Behind each key was a colored 1-W bulb. A minimum force of 0.1 N (10 g) was required to activate the keys. When activated, the keylights flashed off for 0.5 s and an electronic beeper sounded.

Parts 2, 3, and 4. For Parts 2, 3, and 4, the chamber was modified to include a "door" re-

sponse unit. A schematic diagram of the modified response chamber is presented in Figure 1. The right response key was removed, and the hole was covered with sheet metal. The door was fixed onto this as close as was practicable to the position of the removed key. The door consisted of a metal tube frame situated 37 cm from the grid floor to which a microswitch (numbered 1 in Figure 1) was attached. The frame supported two bearing races. Carried in these bearings, and able to rotate, was a horizontal shaft of square metal tubing 17 cm long, 1.5 cm wide, 1.5 cm deep, and situated 33.5 cm from the grid floor. A metal arm (2) was attached at right angles to the horizontal shaft that, when an effective door push was made, contacted the microswitch. This arm protruded 8 cm beyond the front wall via an opening and supported two thin metal bars (4) on which weights could be placed. Running vertically from the horizontal shaft were two

Table 1

Sequence of experimental conditions, the FR schedules and the VI schedules in effect, and the number of sessions spent in each condition.

Condi- tion	FR schedules		VI schedules		Sessions
	Left	Right	Left	Right	
Part 1: Concurrent key-key					
1	1	5	90	90	35
2	1	5	60	180	18
3	1	5	180	60	36
4	1	5	90	90	27
Part 2: Concurrent key-door					
5	1	1	90	90	24
6	1	1	60	180	23
7	1	1	180	60	20
Part 3: Concurrent key-door					
8	5	1	180	60	24
9	5	1	60	180	14
10	5	1	90	90	35
Part 4: Concurrent key-door					
11	1	1	60	180	19
12	1	1	180	60	19
13	1	1	90	90	23

brass rods (3), 0.7 cm wide, 22 cm long, and situated 5.5 cm apart, through which the hens could push their necks and heads. When suspended, the rods hung 4 cm inside the front wall; it was necessary to push them forward 5 cm (measured at the bottom of the rods), or to an angle of approximately 15°, before the metal arm activated the microswitch. This required a minimum force of 0.56 N (57 g; measured 21.5 cm from the pivot). To perform an effective door push, the hens had to push their heads beyond the front wall of the chamber. To allow this, a hole (10 cm by 19 cm) was cut out of the front wall directly below the door frame and 11 cm above the grid floor. A box (numbered 5 in Figure 1), 10 cm wide, 18 cm deep and 29 cm high, was fixed to the rear of the front wall so that it covered the hole.

A 1-W white bulb (6), with a translucent plastic cap, was located at the rear wall of the box. This light was operated as if it were a keylight (i.e., it was lit when the door was operative, turned off during reinforcement, and flashed off for 0.5 s as feedback for an effective door push). An electronic beeper signaled an effective door push.

Procedure

Part 1. All subjects were initially trained to respond on each of two concurrently available keys using hand-controlled delivery of reinforcement. Over the next 27 sessions, the VI schedules associated with each key were increased from VI 15-s VI 15-s schedules to VI 90-s VI 90-s schedules, a changeover delay (COD) was introduced and gradually increased to 3 s, and second-order schedule requirements were added.

Throughout Part 1, the FR requirements remained at FR 1 and FR 5 for the left and right keys, respectively. Commencing an FR 5 requirement rendered the left key inoperative and darkened until the FR 5 requirement had been completed. Completion of an FR 5 requirement resulted in one of two events: If a reinforcer was programmed by the VI schedule, it was delivered; if a reinforcer was not available, the magazine was lit (but not operated) for 0.2 s.

During Part 1, the VI schedules were varied over four successive experimental conditions; these are shown in Table 1, together with the number of days each condition was in effect. Reinforcement consisted of 3-s access to wheat. During reinforcement the magazine was illuminated, the hopper was raised, and the keylights were extinguished. Pecks to darkened keys were ineffective. At the end of Part 1, the door was installed in the chamber.

Parts 2, 3, and 4. During the first 14 training sessions with the door in the chamber, the key was inoperative. Initially, all subjects were trained to push the door by the hand-controlled delivery of reinforcement for successive approximations to the door-push response. Over the next 12 sessions, the VI schedule associated with the door was gradually increased to VI 30 s. Following this, the response key was made operative. By Session 41, the VI schedules in effect on both manipulanda had been increased to VI 60 s, and a COD of 3 s was in effect.

In Parts 2, 3, and 4, the VI schedules were varied over successive experimental conditions, while the FR schedules were kept constant. In Part 2, an FR 1 requirement was associated with both manipulanda. In Part 3, an FR 5 requirement was associated with the key, and an FR 1 requirement was associated with the door. Part 4 was a replication of Part 2. The sequence of experimental events and the num-

ber of days each were in effect are shown in Table 1.

During Parts 2, 3, and 4, the magazine was operated for 3.5 s if initiated by a door push. This gave the hens enough time to move back from the door and still get approximately 3-s access to wheat.

In all parts of this experiment, the VI schedules ran continuously throughout each experimental session until reinforcement was set up by one schedule, at which point both schedules were stopped until that reinforcer was collected. The schedules were therefore dependent (Stubbs & Pliskoff, 1969). All the VI schedules were comprised of 15 intervals that were derived from the arithmetic progression $j + kx$, where $x = 0, 1, 2, \dots, 14$, j is equal to one 15th of the average VI length, and $k = 2j$.

All experimental sessions ended after 30 reinforcements had been obtained or 40 min had elapsed. At least six sessions were conducted each week. The experimental parameters were changed when the behavior of all subjects had met a stability criterion five, not necessarily consecutive, times. The criterion was that the median relative number of responses (i.e., total number of pecks on the left key divided by total number of responses to both manipulanda) over the last 5 days was within 0.05 of the median of the previous five sessions. Thus, a minimum of 14 sessions was required for stability.

In all conditions, and for each response manipulandum, the following measures were taken: the total number of responses (i.e., key pecks and/or door pushes), the amount of time spent responding (timed, in seconds, from the first response on one manipulandum until the first response on the other), the number of reinforcements obtained; the total number of changeover responses, and the number of post-COD responses. For Parts 1 and 3, the number of FR completions made on the key associated with the FR schedule, both including and excluding those within the CODs, was also recorded.

RESULTS

The data analyzed here were from the last 5 days of each experimental condition (these data are presented in the Appendix). All ratios were taken to the left alternative and were

plotted on a logarithmic scale (to the base 10). Because the subjects had very little experience in responding to concurrent second-order schedules, Condition 1 (in which VI 90-s VI 90-s schedules were in effect) was replicated in Condition 4 of Part 1 and the data from this condition were used in the analyses. The data from Part 4 (replication of Part 2) were not systematically different from those obtained from Part 2 and are therefore not included in the analyses (but are presented in the Appendix).

Figure 2 shows both the log FR completion ratios and the log time ratios plotted against the log obtained reinforcement ratios for each hen. In each panel, the unfilled circles represent the data from Part 1, the crosses represent the data from Part 2, and the filled circles represent the data from Part 3. The dotted diagonal lines show strict matching between the ratio of responses or times and the ratio of obtained reinforcements. Least squares best fit lines for each part of the experiment are also shown. The slopes (a) and intercepts ($\log c$) of the lines are shown in Table 2, together with estimates of the percentage of the variance accounted for by the lines and the standard errors of the estimates.

The preference between two different response requirements is indicated by a y -intercept term (the logarithm of c in Equation 1) different from zero. The upper panels of Figure 2 show that all of the lines fitted to the FR completion data from Part 1 have large and positive intercepts. The values of $\log c$ (Table 2) for the FR completion data from Part 1 indicate that, in terms of response measures, each animal exhibited a strong and consistent preference for the FR 1 (key peck) requirement over the FR 5 (key peck) requirement, over and above preferences caused by reinforcement-rate differences. The FR completion data obtained from Part 2 also demonstrate strong and systematic biases towards the FR 1 (key peck) requirement when the alternative was an FR 1 (door push) requirement. The FR completion estimates of bias ($\log c$) for Part 3 were usually close to zero and did not deviate from zero in any particular direction. Thus, generally small and idiosyncratic biases resulted in the response measures when the FR 5 (key peck) and FR 1 (door push) requirements were paired.

Table 2 shows that for all parts of the ex-

Table 2

The slopes (a) and intercepts ($\log c$) of the lines fitted to both the FR completion and time data for Parts 1, 2, and 3. The percentage of the variance accounted for (% VAC) by each line and the standard error of the estimates (SE) are also shown.

Hen	FR completions				Time			
	a	$\log c$	% VAC	SE	a	$\log c$	% VAC	SE
Part 1: FR 1 (key) vs. FR 5 (key)								
61	0.69	0.57	97	0.07	0.73	-0.07	92	0.13
62	0.44	0.74	83	0.12	0.36	0.05	83	0.10
63	0.41	1.01	97	0.05	0.40	0.43	86	0.12
64	0.79	0.72	99	0.04	0.78	0.06	97	0.08
65	0.51	0.79	90	0.11	0.47	0.27	100	0.00
66	0.50	0.68	95	0.07	0.67	0.04	99	0.05
M	0.56	0.75	94	0.08	0.57	0.13	93	0.08
Part 2: FR 1 (key) vs. FR 1 (door)								
61	0.76	0.56	85	0.18	0.83	0.31	97	0.08
62	0.95	0.40	100	0.05	0.92	0.19	96	0.13
63	0.37	0.70	92	0.08	0.38	0.45	66	0.20
64	0.84	0.95	97	0.11	0.88	0.52	99	0.05
65	0.55	0.72	100	0.01	0.37	0.62	67	0.01
66	0.66	0.61	98	0.06	0.69	0.60	87	0.18
M	0.69	0.66	95	0.08	0.68	0.45	85	0.11
Part 3: FR 5 (key) vs. FR 1 (door)								
61	0.85	-0.08	90	0.18	1.03	0.23	98	0.09
62	1.01	-0.25	100	0.01	1.04	0.06	98	0.09
63	0.50	0.00	37	0.46	0.68	0.35	65	0.35
64	0.59	0.14	92	0.11	0.60	0.32	96	0.07
65	0.77	-0.01	98	0.09	0.81	0.32	99	0.05
66	0.85	0.03	79	0.27	0.65	0.34	59	0.32
M	0.76	-0.02	83	0.19	0.80	0.27	86	0.16

periment, only 3 out of 18 of the FR completion slopes fell close to 1.00 (within the range 0.90 to 1.11). The remainder were below 0.90. For all but 2 hens (Hen 63 and 64), the magnitude of the slopes increased from Part 1 to Part 3. This change is evident in the mean a values calculated across subjects for these three sets of conditions (M ; Table 2). However, this trend did not continue into Part 4, where the slopes were close to those obtained in Part 2.

The lower panels of Figure 2 show that the y intercepts of the lines describing the time-allocation data for Part 1 were, for 4 of 6 hens, close to zero. Any large deviations from zero

(e.g., Hens 63 and 65) were in a positive direction, indicating a time bias towards the FR 1 (key peck) alternative. All of the lines fitted to the time-allocation data from Part 2 have large positive intercepts showing strong and systematic time biases towards the FR 1 (key peck) component over the FR 1 (door push) component. The intercepts of the lines describing the time-allocation data from Part 3 were also positive. Thus, in terms of time allocation, there were fairly strong and systematic biases towards the FR 5 (key peck) component when the alternative was a door push. The magnitudes of the slopes for the time-allocation data

Fig. 2. The logarithms of the ratios of FR completions made on each schedule (upper panels) and the logarithms of the ratios of the times allocated to each schedule (lower panels) as a function of the logarithms of the ratios of reinforcements obtained on the two schedules for each bird. All ratios were taken to the left manipulandum. Each data point represents the mean of the last five sessions of a condition. The unfilled circles represent the data from Part 1 (FR 1 vs. FR 5 conditions), the crosses represent the data from Part 2 (FR 1 vs. door conditions), and the filled circles represent the data from Part 3 (FR 5 vs. door conditions). The diagonal dotted lines represent lines with a slope of 1.0. Other lines show least squares fits.

Mean Bird

Fig. 3. The numbers of changeover responses made per minute plotted against the logarithms of the ratios of the reinforcements obtained on each schedule. The data are arithmetically averaged for all 6 birds over the last five sessions of each condition.

(Table 2) exceeded 0.90 in only 4 of 18 cases. Again the increase in the slopes over Parts 1, 2, and 3 did not continue into the replication of Part 2 (i.e., Part 4).

Comparing the upper and lower panels of Figure 2, it can be seen that the FR completion and time-allocation biases obtained from each part of the experiment differed. The extreme biases seen in the FR completion data from Parts 1 and 2 were not generally reflected in the time-allocation measures. On the other hand, more extreme time-allocation biases were obtained in Part 3. There were no systematic differences however, between the slopes of the lines fitted to the FR completion or time-allocation data from each part of the experiment.

The least squares best fit lines appeared to describe both the FR completion and time-allocation data from all parts of the experiment well. The percentage of variance accounted for by the fitted lines (Table 2) ranged from 37 to 100 for the individual hens, and in only nine cases was it less than 85%. The standard error of the estimates was generally small (Table 2).

Figure 3 shows the rates of changeovers as functions of the logarithms of the ratios of obtained reinforcement rates averaged across all 6 birds. The unfilled circles indicate the data from Part 1, the crosses indicate the data from Part 2, and the filled circles indicate the data from Part 3. The averaged data represent the individual trends well. Whereas the rates of changeover responses decreased over the first three parts of the experiment, the data from Part 4 (replication of Part 2) fell between those from Part 2 and Part 3 (Appendix). For Part 1, the maximum rate of changeover occurred when equal VI schedules were programmed. For Parts 2 and 3, however, the changeover rates decreased as the schedule associated with the door got leaner.

DISCUSSION

Because the present data were well described by the lines fitted according to the generalized matching law with differing bias measures (intercepts), it seems clear that different response requirements act as constant sources of bias over a range of reinforcement-rate variations. This was true for both response and time measures. Therefore, the generalized matching law can be extended to describe and predict the relative preference values of several different response forms.

Prediction and Scaling

It is possible to use the response-differential biases obtained in Parts 1 and 2 to predict the biases obtained when the FR 5 (key peck) requirement was paired with a door push (cf. Miller, 1976). Close agreement between the actual and predicted outcomes would constitute strong evidence for regarding response bias as a constant.

The bias expected in the combination FR 5 versus door push can be derived from the FR 1 versus FR 5 and FR 1 versus door-push biases. Specifically, it is the second divided by the first. In logarithmic terms, this is the second log c estimate minus the first. These predicted log biases are given for individual hens and the group for both time and response measures in Table 3. For the group, and for all hens except 62, the response bias predictions are within one standard error of estimate of the obtained values. Hen 62's data are close, but the standard error was very small. The

time bias predictions are also close, with five of the seven being within one standard error of estimate. Prediction at the individual level was not perfect but was clearly good. Thus, if the biases between Responses A and B and B and C are known, then the A versus C response bias can be predicted with reasonable accuracy.

Using the average bias estimates obtained from the first three parts of the experiment, a scale of the relative preferences for the different responses can be constructed. As Davison and McCarthy (1988) suggested, this can be done by assigning an arbitrary value of 1 to the log bias value of one key peck. Using their suggested analysis and converting to ratios, if one key peck has a scale value of 10, an FR 5 (key peck) requirement has a scale value of 1.78, and a door push has a scale value of 2.19. Both of these values are close to 2. Hence, both alternate responses are around one fifth the value of a key peck, or may be thought of as requiring five times the "effort." When the averaged time biases are used, scale values of about 7.4 and 3.5 are found for an FR 5 requirement and a door push, respectively. Thus, scales based on response and time measures differ.

Response Versus Time Bias

The evident differences in the response and time measures are consistent with data from other experiments that have employed asymmetrical response requirements where, in all cases, the response requirement differential produced a more extreme bias in the response measures than in the time measures (Beautrais & Davison, 1977; Davison & Ferguson, 1978; Hanson & Green, 1986; Wheatley & Engberg, 1978). It can be shown algebraically that, when reinforcement rates are equal, the ratio of two different response durations is given by: $D_1/D_2 = (T_1/T_2)(P_2/P_1)$, where the values of T_1/T_2 and P_1/P_2 are the antilogs of the intercepts of the fitted time and response matching lines. To make this prediction, it is necessary to assume that the time spent on a schedule is a product of the number of responses made and the duration of each response. This is equivalent to assuming that no time is spent on other activities, or that any other activities are distributed evenly over time and occupy a constant fraction of any session time, regardless of schedule allocation.

Table 3

The FR completion and time bias values for Part 3 (FR 5 vs. door) predicted from Parts 1 and 2, together with the obtained values and the standard error of the estimates of the obtained values (*SE*).

Hen	FR completions			Time		
	Predicted	Obtained	SE	Pre-dicted	Ob-tained	SE
61	-0.01	-0.08	0.18	0.38	0.23	0.09
62	-0.34	-0.25	0.01	0.14	0.06	0.09
63	-0.31	0.00	0.46	0.02	0.35	0.35
64	0.23	0.14	0.11	0.46	0.32	0.07
65	-0.07	-0.01	0.09	0.35	0.32	0.05
66	-0.07	0.03	0.27	0.56	0.34	0.32
<i>M</i>	-0.09	-0.02	0.19	0.32	0.27	0.16

Using the average time and response bias estimates obtained in Part 1 of this experiment to estimate the duration of the five key-peck response unit relative to one key peck, we get $5.6/1.35 = 4.1$, which suggests that five key pecks take approximately four times as long to emit as one key peck. This result appears to be reasonable, because once the animal starts on an FR 5 requirement there will be four interresponse intervals before it is completed. When equivalent calculations are applied to the bias measures obtained in Part 2 (FR 1 vs. door), we get $4.6/2.9 = 1.59$, which indicates that one door push takes about one and a half times longer to emit than a single key peck. From these values, one can predict that an FR 5 requirement will take around two and a half times as long as a door push. Using the time and response biases obtained from the FR 5 versus door conditions to predict the relative durations of these operants gives $1.9/0.9 = 2.11$. This is close to two and a half. Thus, it appears that the assumptions that were made are reasonable. Clearly, it is the relative response durations that account for the differences between the response and time biases.

Changeovers

Previous studies of performance under concurrent schedules have found that the rates of changeover responses are highest when VI schedules are equal and are lower when the schedules are unequal (Baum, 1974; Catania, 1963; Herrnstein, 1961; Stubbs & Pliskoff, 1969). This pattern was found in Part 1 of the experiment. When the door was present,

however, the pattern changed. The rates of changeover responses tended to be highest when the VI schedule associated with the door was richest and lowest when the schedule associated with the door was leanest. The rates of changeover responses were also generally lower in the door conditions. Hence, the rate of changeover was found to be a function of both the response requirements and the value of the reinforcement-rate ratio. There is no clear explanation for this, but one major difference between the response requirements in this experiment was the amount of force required to operate each of the manipulanda. The key(s) required a force of 0.1 N, whereas the door required a force of approximately 0.56 N. This is a large difference and quite likely had a considerable effect on behavior.

Undermatching

Undermatching occurs frequently in investigations of concurrent-schedule performance; values of a are usually found to be between 0.8 and 1.0 for many species (Baum, 1974; Lobb & Davison, 1975; Myers & Myers, 1977) including hens (Temple, Scown, & Foster, 1995). In the present study, the sensitivity values obtained were generally much lower than this, showing quite extreme undermatching.

Although previous studies using topographically different responses have typically found undermatching, it has not been as extreme. Davison and Ferguson (1978) reported slopes (mean values of a) of 0.87 for both responses and time. Wheatley and Engberg (1978) reported slopes of 0.69 and 0.63 for response and time, respectively. McSweeney (1978), in an examination of the effect of changes in the length of the COD on behavior using a key-peck/treadle-press procedure, also reported undermatching. The mean value of a was 0.70 averaged across all COD values. However, Hanson and Green (1986) obtained slopes close to 1.0 in their examination of concurrent key-peck versus treadle-press performance. Thus, the degree of undermatching found here is probably not due solely to the use of numerically or topographically different responses.

Wheatley and Engberg (1978) attributed their finding of undermatching to the use of a relatively brief 1-s COD. Davison and Ferguson (1978), using a slightly longer (2-s) COD, did find less extreme undermatching, whereas Hanson and Green (1986), using a

2.5-s COD, observed slopes close to 1.0. These findings suggest that the use of a 3-s COD, as was employed here, should have produced fairly close approximations to matching. However, more extreme undermatching than that found by Wheatley and Engberg (1978) resulted. McSweeney's (1978) failure to find matching using a 20-s COD suggests that COD values beyond the 3 s used would not have produced slopes closer to 1.0. In addition, Temple *et al.* (1995) found little change (and some slight undermatching) for COD values between 2 and 15 s using hens. Nevertheless, little is known about the role of the COD in regulating performance in concurrent studies that employ topographically different responses, and it should be investigated further.

Undermatching is also suggested to result from a failure to discriminate between the components (Baum, 1974). In the present experiment, undermatching was less extreme in the conditions in which the responses were topographically dissimilar. Thus, the use of topographically different responses may have enhanced the discrimination of the alternatives.

The degree of undermatching was greatest in the FR 1 (key) versus FR 5 (key) conditions and lowest in the FR 5 (key) versus FR 1 (door) conditions, with the FR 1 (key) versus FR 1 (door) conditions intermediate. Thus, undermatching was lowest when the different responses took the most similar durations (*i.e.*, FR 5 vs. door). However, it is unclear how much the different times taken, or the requirement to complete an FR requirement once it was started, may have contributed to the undermatching found.

For each part of the experiment, the results appeared to be well described by the generalized matching law. However, the finding that both bias and sensitivity changed systematically across conditions presents a problem in interpretation. Although bias has consistently been shown to be manipulable under a range of different parameter variations, nothing within the generalized matching law allows us to predict the degree of undermatching. As Davison and Ferguson (1978) suggested, it is possible that undermatching might result because some responses are more sensitive to reinforcement than others. This is supported by both the present results and those of Beauthrais and Davison (1977), in which the sensitivity

of the behavior measures decreased as the FR requirement on the left key was increased. It could be that the two parameters—sensitivity and bias—do not vary independently when response topography changes.

In conclusion, the present results show that different response requirements act as approximately constant, quantifiable sources of bias in concurrent-schedule performance. It was also shown that the generalized matching law can be extended to predict and scale animals' preferences for different response forms. Although the preference scales based on response and time measures differed, these differences were accounted for by the temporal extent of the operants. It is suggested that this method of scaling allows comparison of preference results based on topographically different responses. In addition, it was found that a door-push response can be used successfully to study preferences in the domestic hen.

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APPENDIX

Numbers of FR completions made, time spent responding, reinforcements obtained, and the numbers of changeover responses (CO) all summed over the last five sessions of each condition.

Condition	Hen	FR completions		Time (s)		Reinforcements		COs
		L	R	L	R	L	R	L > R
Part 1								
2	61	3,567	505	4,718	3,009	110	40	287
	62	2,941	394	5,693	3,886	109	41	240
	63	4,025	235	6,972	1,450	114	36	150
	64	5,321	477	5,937	2,173	110	40	203
	65	2,844	295	5,741	1,837	113	37	162
	66	1,648	222	5,905	2,679	110	40	174
3	61	1,546	800	2,162	5,459	44	105	206
	62	2,034	650	3,947	4,677	39	110	280
	63	3,696	552	5,337	2,762	37	113	252
	64	2,855	1,264	2,978	5,319	39	110	235
	65	1,814	568	4,197	3,790	38	112	259
	66	1,236	474	3,236	5,826	38	112	294
4	61	3,082	709	4,356	3,990	76	74	359
	62	3,283	457	4,500	4,700	77	73	349
	63	3,090	333	6,952	3,549	74	75	207
	64	4,807	854	4,101	4,282	74	76	246
	65	2,928	380	5,771	3,073	76	74	286
	66	1,888	340	4,521	4,599	75	75	310
Part 2								
5	61	3,148	1,189	5,875	3,270	75	74	288
	62	2,074	897	5,048	4,109	75	75	233
	63	5,289	916	7,345	1,806	76	74	178
	64	6,840	968	7,341	2,038	74	74	203
	65	3,848	741	6,795	2,261	74	76	200
	66	2,532	695	7,053	2,466	76	74	170
6	61	4,324	517	7,068	1,640	104	42	135
	62	2,532	370	7,618	1,697	111	40	101
	63	2,021	323	9,279	2,914	88	27	96
	64	8,145	314	8,418	976	114	36	93
	65	4,203	438	8,272	1,136	103	46	131
	66	2,582	310	7,095	830	93	33	85
7	61	2,641	1,262	4,367	4,396	42	108	268
	62	1,073	1,121	3,697	5,745	38	112	268
	63	3,845	1,212	5,025	3,262	39	110	233
	64	5,186	1,389	4,981	4,237	37	113	248
	65	2,156	735	7,694	2,312	39	111	212
	66	1,872	983	8,048	3,937	33	109	242
Part 3								
8	61	468	1,092	3,063	5,356	41	109	200
	62	281	1,358	2,597	7,116	40	110	166
	63	737	853	5,491	3,794	36	114	194
	64	887	1,063	5,460	4,454	40	110	199
	65	566	1,452	3,991	4,694	37	113	167
	66	512	898	6,887	4,334	39	104	156
9	61	1,183	501	7,252	1,636	111	39	124
	62	575	344	7,564	2,302	112	38	106
	63	788	297	9,437	1,383	96	32	81
	64	1,312	483	7,579	1,884	109	41	105
	65	775	355	10,426	1,722	106	31	105
	66	826	286	11,798	2,194	108	42	107
10	61	529	834	7,629	3,564	77	72	238
	62	427	781	5,781	4,537	73	77	204
	63	403	961	5,130	4,503	74	76	200
	64	1,057	906	6,368	3,325	78	72	211
	65	696	631	7,700	3,332	75	75	146
	66	481	739	6,814	5,696	75	75	229

APPENDIX

(Continued)

Condition	Hen	FR completions		Time (s)		Reinforcements		COs
		L	R	L	R	L	R	L > R
Part 4								
11	61	3,556	563	15,571	1,007	106	44	98
	62	2,394	1,015	6,861	2,451	111	39	166
	63	5,642	553	7,722	1,174	113	37	99
	64	7,011	772	7,919	1,248	112	38	114
	65	5,910	300	8,854	741	111	39	81
	66	2,664	837	8,789	1,671	114	36	151
12	61	1,740	946	7,273	4,460	43	107	190
	62	1,538	1,575	4,140	5,116	40	110	266
	63	2,667	1,105	5,297	3,703	36	114	191
	64	3,706	1,987	5,934	3,442	40	110	205
	65	2,450	934	6,050	3,841	35	115	185
	66	1,547	1,215	6,095	5,168	41	109	237
13	61	2,639	740	9,186	2,140	74	76	166
	62	1,707	1,601	4,931	5,115	75	75	261
	63	5,062	968	6,961	2,616	75	75	189
	64	5,367	1,247	7,861	2,080	76	74	159
	65	4,223	627	7,661	2,576	73	77	219
	66	2,085	1,292	6,341	3,019	75	75	216