CONCURRENT-SCHEDULE PERFORMANCE IN DAIRY COWS: PERSISTENT UNDERMATCHING

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Performance of dairy cows responding under concurrent variable-interval variable-interval schedules of food delivery was examined, with results analyzed in terms of the generalized matching equation. In Experiment 1, bias measures indicated that crushed barley was preferred over mealmeal when these foods were available under the alternative schedules. For whole-session data, substantial undermatching of response and time-allocation ratios to obtained reinforcement ratios was evident. Postreinforcement pause time ratios approximately matched obtained reinforcement rates. Subtracting these times from total time-allocation values yielded net time-allocation ratios that undermatched obtained reinforcement ratios to a greater degree than did whole-session time-allocation ratios. In Experiment 2, substantial undermatching was evident when the same foods (hay for 2 cows, crushed barley for 2 others) were available under the alternative schedules. Food-related activities and other defined behavior not related to food were quantified by direct observation, and were found to occupy a substantial proportion (roughly 40% to 80%) of experimental sessions. Subtracting the time spent in these activities from the time allocated to each component schedule did not reduce the degree of undermatching obtained. Across all conditions in both experiments, slopes of regression lines relating behavioral outputs to environmental inputs characteristically were below 0.6, which agrees with prior findings and suggests that, contrary to suggestions in the literature, undermatching in dairy cows is not the result of using different foods under alternative schedules or differential pausing under those schedules.

Key words: matching equation, undermatching, food preference, variable-interval schedule, nose-press response, dairy cows

Over the past two decades, studies of performance under concurrent schedules have played an important role in the experimental analysis of behavior (Davison & McCarthy, 1988; de Villiers, 1977). Data collected under concurrent schedules are characteristically analyzed quantitatively via various forms of the matching equation, which relates behavioral outputs to environmental inputs. Specifically, the generalized matching equation (Baum, 1974) relates an organism's allocation of time (or behavior) to alternative schedules to the number of reinforcers received under those schedules. Expressed in logarithmic coordinates, the equation takes the form

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

where B is the measure of behavior (re-

sponses or time) under a component schedule, r is the obtained reinforcement rate under a component schedule, and the two alternative component schedules are designated by the subscripts. The slope of the line fitted to the data, a , is a measure of the degree to which behavior is influenced by differences in reinforcement rates (i.e., the sensitivity of behavior to reinforcement). $\log c$, the intercept, is an estimate of bias in behavior for one or the other schedule.

Strict matching, as proposed by Herrnstein (1970), requires a to be equal to 1.0. When a is less than 1.0, undermatching is evident. A large body of data, most collected with pigeons responding under concurrent variable-interval variable-interval (VI VI) schedules of food delivery, is well described by the generalized matching equation, although some degree of undermatching is evident in many studies, with values of a around .80 being common (Baum, 1979; Davison & McCarthy, 1988; Mazur, 1991; Williams, 1988). The variables responsible for undermatching, and its theoretical significance, are debatable.

The present study further explored the concurrent-schedule performance of a spe-

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cies that has been reported to produce substantial undermatching, the dairy cow (*Bos taurus*). In the single study that examined matching in this species, Matthews and Temple (1979) obtained values of a that ranged from .30 to .55 in 6 cows. Moreover, although different foods were associated with each alternative, they found only slight preferences (i.e., biases) for one food over the other. Experiment 1 of the present study examined concurrent VI VI performance in dairy cows exposed to more disparate foods than those used by Matthews and Temple. One purpose of this experiment was to ascertain whether bias would be observed across a range of schedule values when very different foods (crushed barley and meatmeal) were available. The second purpose was to determine whether the use of foods different from the chopped hay and dairy meal used by Matthews and Temple would change the degree of undermatching obtained.

Although they did not actually measure these activities, Matthews and Temple (1979) reported that their subjects spent a considerable time in eating and masticating the obtained food, and these activities may have contributed to the undermatching observed with the specified operant. Specifically, if the time spent in such activities was excluded from analysis and a measure of the actual time spent responding was obtained, it is possible that the apparent undermatching would be reduced or eliminated. Experiment 1 explored this possibility by measuring postreinforcement pause times and analyzing time-allocation data with and without the inclusion of postreinforcement pauses. It also examined the use of bias measures under concurrent schedules to quantify food preferences. Doing so was of interest because of the emerging worldwide concern for the well-being of farm animals and the possible utility of operant techniques in the evaluation of animal welfare (Dawkins, 1983a, 1983b; Kilgour, Foster, Temple, Matthews, & Bremner, 1991).

EXPERIMENT 1

METHOD

Subjects

Three Friesian cows (1, 2, and 3) and 2 twin Jersey cows (4 and 5) served as subjects.

All cows had previous experience under concurrent schedules and were not lactating or pregnant during the study. They received restricted grazing on 0.2 ha of pasture each day after the experimental session. The duration of access to pasture varied between 30 min and 3 hr, depending on the amount of grass available. Seasonal variations in pasture required that the cows occasionally receive supplemental feeding of approximately 2 kg of hay per animal per day. The cows were weighed once a week, and alterations in grazing times and hay feedings were arranged to maintain relatively consistent weights. Water was freely available except in the experimental chamber.

Apparatus

The experimental apparatus was similar to that used by Matthews and Temple (1979). In brief, the experimental chamber was about 3 m long and 2 m high, and had walls 1.65 m high. There was no ceiling immediately above the chamber, but the laboratory roof was approximately 4 m above the chamber floor. Two 40-W fluorescent tubes suspended 3.5 m above the floor supplied ambient illumination.

A feed delivery unit with two hoppers, described in detail by Cate, Mullord, Temple, and Matthews (1978), permitted the presentation of equal volumes of two foods. The foods presented in this study were commercially produced crushed barley and meatmeal. The crushed barley was delivered in small pellets, and the meatmeal was delivered as a powder. Food delivery was accompanied by an audible hiss from the pneumatic ram that raised the hoppers, and the food was available 1.5 s after the ram was activated. The food hopper remained raised for the specified period, after which another audible hiss (0.5 s) accompanied its lowering.

Two 12-cm nose plates, 85 cm apart at their midpoints, were located at an angle of 30° to the horizontal behind the food delivery unit. A minimum force of 0.2 N operated each plate and produced an audible sound. Arrangement of experimental events and data collection were accomplished by electromechanical and solid-state equipment located in an adjacent room.

Table 1

Experimental conditions arranged in Experiment 1.

Condition	Food ^a		VI length (s)		Session duration (min)	Total sessions
	Left	Right	Left	Right		
1	CB	CB	90	90	20	35
2	CB	MM	90	90	20	23
3	CB	MM	120	90	20	19
4	CB	MM	150	90	20	45
5	CB	MM	240	90	20	60
6	CB	MM	90	90	30	24
7	CB	MM	90	30	30	20
8	CB	MM	90	15	20	27
9	CB	MM	90	180	20	17
10	CB	MM	90	240	20	26
11	CB	MM	90	360	30	21
12	CB	MM	90	90	30	27
13	CB	MM	30	90	20	19
14	CB	MM	60	90	30	22

^a CB indicates crushed barley; MM indicates meatmeal.

Procedure

All cows had previous histories of nose-press responding under concurrent schedules; therefore, no initial training was required. Throughout the experiment, dependent concurrent VI VI schedules of food delivery were arranged on the two response plates. The pairs of schedules, in their order of presentation, are shown in Table 1. All schedules comprised 12 intervals from the arithmetic progression, a , $a + d$, $a + 2d$, $a + 3d$, and so on, with $a = 8$ s in all instances, and d chosen to give the appropriate average interfood interval. The schedules were arranged dependently (Stubbs & Pliskoff, 1969), so that when an interval had elapsed on either of the schedules, both schedules stopped until food was delivered. A changeover delay (COD) of 3 s was used in all conditions, and all food deliveries were 3 s in duration. The COD specified that food could be earned no sooner than 3 s after switching from one plate to the other.

In Condition 1, VI 90-s schedules were arranged on both response plates, with crushed barley available in both feeders. In all subsequent conditions, crushed barley was available dependent on presses of the left plate and meatmeal was available dependent on presses of the right plate. The component schedules for Conditions 2 through 14 were changed systematically by alternately holding the schedule arranged on the left plate con-

stant at VI 90 s and varying the schedule arranged on the right plate, and then holding the schedule arranged on the right plate constant at VI 90 s while varying the schedule arranged on the left plate (see Table 1). In various conditions, component schedule values of 15, 30, 60, 90, 120, 150, 180, 240, and 360 s were arranged concurrently with a VI 90-s component schedule. The session duration for the first five conditions was 20 min; all subsequent sessions were 30 min unless this resulted in satiation and irregular responding before the end of the session, in which case sessions were reduced to 20 min. Table 1 shows session durations throughout the study.

Each pair of component schedules was in effect until the median of the relative number of responses on one plate (responses on one plate divided by total responses) for the last five sessions did not differ by more than 0.05 from the median of the five sessions immediately prior to the last five sessions. Conditions were changed when all cows had met this criterion five, not necessarily consecutive, times.

The number of responses and the time allocated to each component schedule were recorded for each session. Time was allocated to a particular schedule from the instant that a response occurred on that schedule until a response occurred on the other schedule, throughout the session. The time to the first response following each food delivery, termed the postreinforcement pause, was also recorded. A given postreinforcement pause was allocated to the schedule under which the immediately prior food delivery had been earned, regardless of the plate on which the response that ended the pause occurred. Pause times were subtracted from the total time allocated to each schedule to yield the net times allocated to those schedules.

RESULTS

Raw data for Experiment 1 appear in Appendix A. Figure 1 shows whole-session response and time ratios for individual cows plotted against reinforcement ratios under all conditions of Experiment 1. In this and other figures, data for each of the final five sessions of exposure to each condition are depicted. Lines of best fit for the data, fit by the method of least squares, are shown, as are the equations for the lines of best fit. The first

term on the right side of the equation (e.g., 0.20 for Cow 1, responses) indicates the y intercept (i.e., bias), and the second term (e.g., 0.35 for Cow 2, responses) indicates the slope. Two measures of the goodness of fit are provided: VAC, the percentage of variance accounted for, and SE , the standard error of the estimate of y . When slopes are shallow, as most are here, the percentage of variance accounted for is artificially reduced and is not a good indication of the fit of the line. In these cases, the standard error of estimate provides a better indication of fit, and this measure can be compared meaningfully across lines with different slopes.

In general, all of the regression lines provide reasonable descriptions of the data. For both response and time measures, substantial undermatching was observed in the whole-session data for all subjects. The response-measure slopes ranged from 0.35 to 0.57 across individual cows, and the time-measure slopes ranged from 0.51 to 0.70. For each cow, the slope for the time measure was greater than that for the response measure. Across cows, the intercepts of the fitted lines ranged from 0.20 to 0.56 for the response measure and from 0.21 to 0.37 for the time measure. For 4 of 5 cows, the intercept was smaller (i.e., bias was less) with the time measure.

Postreinforcement pause ratios and net response time ratios, graphed as a function of obtained reinforcement ratios, are shown in Figure 2. Postreinforcement pause ratios approximately matched obtained reinforcement ratios; slopes of lines relating these measures ranged from 0.87 to 1.04 in individual cows. Relatively little bias was evident, with intercepts ranging from -0.15 to 0.08 . This indicates that the cows paused for a similar time before initiating responding after a food delivery, regardless of whether the food was crushed barley or meatmeal.

In general, individual postreinforcement pauses for individual cows ranged from approximately 20 to 30 s per food delivery. Re-

moving postreinforcement pauses from the whole-session time-allocation data (i.e., calculating net response times) increased the degree of undermatching observed in all subjects. With net response times, slopes ranged from 0.14 to 0.42 for individual cows. Biases were larger with the net time data than with the whole-session time-allocation data. With the former measure, intercepts for the 5 cows ranged from 0.37 to 0.62.

DISCUSSION

As in a prior experiment (Matthews & Temple, 1979), dairy cows responding under concurrent VI VI schedules of food delivery exhibited substantial undermatching. Slopes of regression lines relating time (and response) allocation ratios to reinforcement ratios were similar in the two studies, with most slopes below 0.60, indicating a comparable degree of undermatching. Thus, the present data suggest that the undermatching observed by Matthews and Temple was not due to the specific schedules and foods that they examined. Moreover, omitting postreinforcement pauses from the calculation of time-allocation ratios increased rather than decreased the degree of undermatching obtained. Baum (1979) has suggested that differential pausing under the alternative schedules may contribute to undermatching. In the present study, the cows did not respond for roughly 20 to 30 s after each food delivery, regardless of whether crushed barley or meatmeal was delivered. As a result, overall pause times were longer under the richer alternative schedule, and the time spent in pausing under an alternative was roughly proportional to the number of food deliveries earned under that schedule. Such a pattern could not contribute to undermatching.

The foods available in the present study (meatmeal and crushed barley) are very different, and it was of interest to determine to what degree the cows preferred one over the other. $\log c$ (Equation 1) can be considered

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Fig. 1. The logarithms of the whole-session response (left) and time (right) ratios plotted against the logarithms of the reinforcement ratios for individual cows under all conditions of Experiment 1. Data represent the final five sessions of exposure to each pair of VI schedules arranged. Lines of best fit for these data, fit by the method of least squares, are shown, as is the equation for each line. VAC represents the percentage of variance accounted for by the equation; SE represents the standard error of the estimate of y .

to be made up of bias resulting from at least two sources: bias resulting from the different feeds ($\log q$) and bias resulting from a tendency to respond more on one plate than on the other when all else is equal (side bias, $\log b$). These sources of bias are shown in the following equation:

$$\log (B_1/B_2) = a \log (r_1/r_2) + \log b + \log q. \quad (2)$$

As Matthews and Temple (1979) indicated, the logarithms of the response (or time) ratios from a condition with the same food available under equal-length VI schedules, as in Condition 1 of the present study, can be used to give point estimates of position biases ($\log b$). This is so provided that log reinforcement ratios for that condition are close to zero and, hence, disappear from Equation 2. Inspection of the current data for Condition 1 indicated that log reinforcement ratios ranged from -0.02 to 0.00 . Because crushed barley was available under both schedules in that condition, $\log q$ was approximately zero. Given this, $\log c$ (Equation 1), the intercept of the line fitted to the data from the conditions with different feeds, is the sum of position bias ($\log b$) and any bias resulting from feed differences ($\log q$). Therefore, $\log b$ can be subtracted from $\log c$ to obtain an estimate of $\log q$. Calculating the antilog of $\log q$ indicates the ratio by which one food is preferred over the other.

Position biases calculated from the data for Condition 1 were relatively small and similar for response and time measures. For Cows 1 through 5, the antilogs of $\log q$ were 1.9, 1.6, 4.0, 2.4, and 2.7, respectively, for the response measures and 1.3, 1.4, 2.1, 2.4, and 2.0, respectively, for the time measures. That is, crushed barley was preferred over meatmeal by ratios of approximately 1.6 to 4.0 with the response measures and by ratios of 1.3 to 2.4 for the time measures. With preference measured in terms of net time allocated to the two schedules (with position bias removed), crushed barley was preferred over meatmeal

by ratios ranging from 1.9 to 4.2. Thus, removing postreinforcement pause times increased the bias measure, and apparent preference, considerably. Interestingly, although the cows preferred crushed barley to meatmeal, they paused for a similar period after receiving each food.

Although the relevance of preference to animal welfare has been emphasized, the techniques used to assess it are often crude and of questionable sensitivity (e.g., Bradshaw & Poling, 1991; Dawkins, 1983b). The procedures used in this experiment, which were also used by Matthews and Temple (1979), appear to offer a sensitive and reasonably practical method for the assessment of food preferences in dairy cows and other species.

EXPERIMENT 2

This experiment examined the performance of cows under concurrent VI VI schedules with only one type of food available. Both de Villiers (1977) and Baum (1974, 1979) suggested that deviations from strict matching may result from procedural variations, and most studies that have obtained strict matching used a single food. Rachlin, Kagel, and Battalio (1980) specifically suggested that, because different foods were always correlated with the two alternative schedules arranged by Matthews and Temple (1979), the substantial undermatching they obtained may have resulted from the different substitutabilities of the different foods. Therefore, it is of interest to determine how cows behave with a single food available. Because it has been suggested that insufficient COD length may contribute to undermatching (Baum, 1974, 1979; de Villiers, 1977), Experiment 2 used a longer (5-s) COD than that used in Experiment 1 or by Matthews and Temple (1979).

This experiment also collected data on behavior other than the required operant. Although differential pausing immediately following food delivery did not contribute to the

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Fig. 2. The logarithms of the postreinforcement pause ratios (left) and net response-time ratios (right) as a function of the logarithms of the obtained reinforcement ratios across all conditions of Experiment 1. Net time values were obtained by subtracting postreinforcement pause time from the total time allocated to an alternative schedule. Other details are as in Figure 1.

undermatching observed in Experiment 1, differential pausing at other times may have done so. Experiment 2 determined through direct session-long observation whether cows paused for different periods under different VI schedule values, and what they did during those periods.

METHOD

Subjects and Apparatus

A set of twin Jersey cows (4 and 5) and 2 Friesian cows (6 and 7) served as subjects. The Jerseys had been subjects in Experiment 1. In general, animals were maintained as in Experiment 1, although short pastures required feeding each subject approximately 4.0 kg of hay per day outside the experimental session. The feeding regimen used in both experiments was sufficient to establish food (crushed barley, mealmeal, hay) as a reinforcer, and probably is best construed as involving moderate food deprivation. There are, however, no standard establishing operations for food reinforcement in cattle, and it is not possible to compare meaningfully the level of deprivation arranged in the present studies to the levels arranged with other species in prior investigations.

The apparatus was similar to that described in Experiment 1. For Experiment 2, an observation window (52 cm wide and 85 cm high) was situated in the laboratory wall about 300 cm above the chamber floor, and a 10-pen event recorder, operated automatically and by human observers, was added to the data-collecting apparatus. In Experiment 2, both food hoppers contained either chopped hay with an average length of 2 to 3 cm or commercially supplied crushed barley. The hay was harvested 4 months before the experiment, and was chopped to limit spillage when eaten from the food hoppers.

Procedure

Shaping was used to engender presses of the response plate by the 2 experimentally naive cows; no such training was required for the experienced animals. Once pressing occurred reliably on each plate under a schedule on which every nose poke produced food, crushed barley was substituted for hay for 2 cows (5 and 7), and crushed barley was used as the reinforcer for these animals for the bal-

Table 2
Experimental conditions arranged in Experiment 2.

Condi- tion	VI length (s)		Total sessions ^a
	Left	Right	
1	90	90	17, 18, 17, 14
2	60	120	18, 23, 17, 14
3	120	60	14, 18, 17, 15
4	30	150	16, 22, 14, 24
5	150	30	16, 15, 17, 17

^a Data for Cows 4, 5, 6, and 7, respectively.

ance of the study. Hay continued to be used as a reinforcer for the other 2 cows. Throughout Experiment 2, food deliveries were 5 s in duration, and a 5-s COD was arranged.

Table 2 summarizes the conditions of Experiment 2. During the experiment proper, concurrent dependent VI VI schedules, as described in Experiment 1, were arranged during daily 20-min sessions. Schedule pairs were arranged so that the programmed relative reinforcement rates (the number of reinforcers programmed on one schedule divided by the total number of programmed reinforcers) ranged from 0.09 to 0.91. Condition 1 had equal reinforcement rates on both schedules, and Conditions 2 through 5 involved systematic alternations of schedule values. Each pair of schedule values was in effect until the stability criterion described in Experiment 1 was attained. However, in Experiment 2, conditions changed for each cow as soon as it met the stability criterion; in Experiment 1, conditions were altered only when the performance of all animals was stable.

The number of responses on each component schedule, the time allocated to each component schedule, and the number of reinforcers earned under each component schedule were recorded automatically for each session. Responses on each plate and food deliveries also were recorded on the event recorder, through which paper passed at 1 mm per second.

Additional data were collected by watching the cows through the observation window. Direct observation by a single observer was arranged for at least the final five sessions of each experimental condition. For at least one of these sessions during the first three experimental conditions, a second observer also independently observed the cows. In recording

Table 3

Categories of behavior recorded in Experiment 2.

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1. Food-related behavior
 - A. Chewing food: Visible movement of the lower jaw in relation to the upper jaw in a sideways or up-down motion.
 - B. Picking and licking food: Picking and licking food from the panels of the delivery unit or the floor with the mouth or tongue.
 2. Other behavior
 - A. Turning away from the response unit: Occurs when the cow's front hoofs are not within 2 m of the unit. (To aid recording, a mark was placed on each side wall 2 m from the unit.)
 - B. Inserting the nose into a food hopper when food was not available.
 - C. Licking its own body.
 - D. Scratching its neck or body against the corners of the response unit, floor, or wall.
 - E. Sniffing the delivery unit, the floor, or the walls.
 - F. Bellowing.
 - G. Urinating.
 - H. Defecating.
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data, the observers depressed a switch that displaced a pen on the chart recorder when behavior selected for observation occurred and released the switch when the activity ceased. Two general categories of behavior, based on preexperimental observations, were scored—food-related behavior and other behavior. The specific activities in these categories and their definitions are listed in Table 3.

The observers activated specific pens on the event recorder to record the time spent chewing food, picking and licking food, and engaging in other behavior. Responses and food deliveries under the alternative schedules automatically activated other pens. Thus, the event records provided sufficient information to determine the schedule under which a cow had been responding when food-related activities or other defined behavior occurred, and to assign these activities to the two alternative schedules. For each session, event records were analyzed to determine the time spent in food-related activities and other behavior when each cow was responding on the schedule arranged on the left and right plates.

None of the observed activities were performed simultaneously with the designated operant response, except in the case of Cow 7. For this animal, the time spent chewing food overlapped with bursts of postreinforcement responding. In the extraction of data, the time spent in these simultaneous activities

was allocated to the time spent responding. At the end of the 5-s hopper activation, all cows spent approximately 1 to 2 s with their muzzles remaining in the food hopper. This behavior was recorded as chewing food.

The event records were measured by two people to determine the number of seconds spent in each of the major behavioral categories of interest. If they disagreed on the number of seconds encompassed by a particular activity, the record was measured again until agreement ensued. For sessions in which two observers recorded data separately, interobserver agreement coefficients were calculated according to the procedure described by Harris and Lahey (1978). With this procedure, the millimeters of tape in which all event pens were in the same position for both observers (agreement) was compared with the millimeters of tape in which one or more pens were in different positions (disagreements). Agreement coefficients ranged from .89 to .97 for the 12 sessions in which two observers recorded data; coefficients in this range indicate acceptable levels of agreement (Harris & Lahey, 1978).

RESULTS

Raw data for Experiment 2 are provided in Appendixes B and C. Figure 3 shows entire-session response and time ratios for individual cows plotted against reinforcement ratios. The data for each of the last 5 days of each condition are shown separately here and in all other figures. With the exception of the response data for Cow 7, the regression equations provide a good description of obtained results. Regardless of whether the food delivered was hay or crushed barley, substantial undermatching was evident in all animals. Slopes for response measures ranged from 0.15 to 0.58 for individual animals, and those for time measures ranged from 0.45 to 0.58. The response data for Cow 7 are the most variable and show the greatest degree of undermatching and a large bias ($\log c = 0.36$). The time measures for this cow are similar to those of the other subjects, although they still have the lowest slope. For 3 cows, the slopes for the time measures were greater than those for the response measure; slopes were similar for the 4th animal.

Although time spent in food-related behavior was recorded as either time spent chewing

or time spent picking and licking, the two classes of behavior generally occurred together, mainly after each food delivery. Because of their high level of covariation, they were grouped together for analysis. Figure 4 presents the ratios of the times spent in food-related and other defined behavior as functions of the ratios of the obtained reinforcement rates for each condition. The parameters of the fitted lines and the measures of fit appear on the graph.

The time spent in food-related behavior was an orderly function of the obtained reinforcement rate ratios. In all cases, these functions undermatch, but do so to a lesser degree than the total time measures. Relatively little time was spent in other defined behavior, which was variable within and between subjects and showed no consistent relationship to changes in the obtained reinforcement-rate ratios for all subjects.

The time spent in all observed behavior (food-related and other defined) was subtracted from the total time allocated to the alternative on which the last response had occurred (i.e., the total time allocated to each alternative schedule) to provide a measure of the time in which no defined behavior, except the specified operant (plate pressing), occurred. We refer to this measure as the net response time. Figure 4 shows the ratios of the net response times as functions of the reinforcement ratios. The parameters of the equations that describe regression lines fitted through these data, and measures of fit, are provided on the graph. For all cows, substantial undermatching, with slopes ranging from 0.10 to 0.43, was evident. Moreover, slopes were consistently lower (i.e., the degree of undermatching was higher) with the net response time measure than with the whole-session time measures.

DISCUSSION

In this experiment, the generalized matching equation provided a good description of the whole-session data (time and response allocation) and the data obtained when the

time spent in food-related activities and other defined behavior was excluded from analysis. As in Experiment 1 and in an earlier study by Matthews and Temple (1979), however, substantial undermatching was evident. Undermatching occurred in Experiment 2 despite the fact that the same food was arranged under the alternative schedules. This suggests that the "extreme" undermatching reported by Matthews and Temple (and in Experiment 1 here) was not due to the use of different foods, as Rachlin et al. (1980) had suggested.

An important aspect of Experiment 2 was the observation and recording of cows' behavior during experimental sessions. One major finding was that the cows spent large amounts of time not emitting the required operant (not responding). For all cows, the amount of time spent not responding ranged across conditions from 41% to 81% of the total session time. Most of this time was spent in behavior defined as food related; following nearly all food deliveries, the cows spent a considerable period of time in picking at, licking, and chewing the hay or crushed barley. A second major finding was that subtracting the time spent in food-related activities and in other defined behavior from the total session time did not reduce the degree of undermatching observed. In fact, stronger undermatching was evident in the net time-allocation measures than in the total time-allocation measures.

GENERAL DISCUSSION

The generalized matching equation accurately describes the relationship between environmental inputs and behavioral outputs in many previous studies of concurrent VI VI performance (Baum, 1979; Davison & McCarthy, 1988; Mazur, 1991; Williams, 1988), and does so with respect to the data obtained in the present experiments. However, in the present study and in a prior study with cows (Matthews & Temple, 1979), substantial undermatching was evident. This outcome occurred regardless of whether the alternative

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Fig. 3. The logarithms of the whole-session response (left) and time (right) ratios plotted against the logarithms of the reinforcement ratios for individual cows under all conditions of Experiment 2. Two cows received hay under all schedule pairs; 2 others received crushed barley (CB). Details are as in Figure 1.

VI schedules arranged the same or different foods, whether or not time spent in other activities was subtracted from total session time, and whether the COD was 2, 3, or 5 s. Taken together, the results of the study by Matthews and Temple and those of the present experiments provide substantial evidence that dairy cows responding under dependent concurrent VI VI schedules of food delivery undermatch, characteristically producing a values below 0.6 for both time and response ratios.

Why dairy cows undermatch to this degree is unknown. No other ruminant species has been studied under concurrent schedules of reinforcement that would permit a matching analysis, although strict matching has been observed in another large bulk-feeding herbivore (the horse) responding under schedules similar to those arranged in the present study (Dougherty & Lewis, 1992). Dougherty and Lewis speculated that the difference in the results they obtained with horses and those that Matthews and Temple (1979) obtained with cows may have been due to the use of different COD values—2 s with the cows and 5 s with the horses. The use of a 3-s COD in Experiment 1 and a 5-s COD in Experiment 2 did not produce substantially less undermatching than that observed by Matthews and Temple, although it is possible that longer CODs would do so.

Both Baum (1974, 1979) and de Villiers (1977) have speculated that the use of CODs of insufficient length may lead to undermatching, although the relation between concurrent-schedule performance and COD length is not a simple one. For example, Allison and Lloyd (1971) and Silberberg and Fantino (1970) reported no change in the degree of matching obtained with pigeons over the range of COD values they examined (2.0 to 12.5 s and 0.875 to 3.5 s, respectively). Moreover, Baum (1982) concluded that there is every chance of obtaining matching with no COD programmed, as long as sufficient care is taken with procedures, and some stud-

ies have reported strict matching with no programmed COD (e.g., Heyman, 1979). In those studies in which the degree of undermatching decreased with increases in COD length, the magnitude of the effect was not large, with increases in slopes not exceeding 0.1 to 0.2 characteristically reported (e.g., Shull & Pliskoff, 1967; Silberberg & Schrot, 1974). Given these findings, it appears unlikely that increasing the COD under conditions similar to those arranged in the present study would be sufficient to produce strict matching in dairy cows, although the possibility does merit investigation.

Some data suggest that the use of arithmetic VI schedules contributes to undermatching, although reported differences in slopes under comparable arithmetic and exponential schedules were less than 0.2 (Taylor & Davison, 1983). Therefore, it is improbable that the use of exponential rather than arithmetic schedules under conditions similar to those arranged in the present study would produce strict matching in dairy cows. With sufficient other modifications, however, perhaps including the use of CODs longer than 5 s, it is certainly possible that strict matching would be obtained.

Although it may be unfamiliar to many behavior analysts, there is a substantial and growing literature that describes the use of operant procedures with farm animals (for a review see Kilgour et al., 1991). Such procedures are appropriate for determining whether particular stimuli can be detected by farm animals and, if so, whether they are "important" to those animals, in the sense of having the capacity to serve as positive or negative reinforcers. Dawkins (1983a, 1990) has argued that the degree of an animal's motivation to perform a particular activity or to secure access to a particular stimulus is relevant to the importance of that behavior or stimulus to the animal's welfare. Specifically, she has argued that the "price" an animal will pay to attain access to (or escape from) a sit-

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Fig. 4. The logarithms of the ratios of the times spent in food-related and in other defined activities (left) and net time-allocation ratios (right) as functions of the logarithms of the ratios of the obtained reinforcement rates for individual cows under all conditions of Experiment 2. Net time values were obtained by subtracting time spent in food-related and other defined behavior from the total time allocated to an alternative schedule. Other details are as in Figure 1.

uation can provide a measure of how the animal "feels" about the situation. By analogy with the concepts of economics, an animal that shows inelastic demand for an environmental event is demonstrating that the event is a need rather than a luxury. Hence, in the interest of the animal's welfare, access to that event should be provided.

Dawkins has also suggested (e.g., 1983b) that, all else being equal, an animal's welfare is improved by giving it access to stimuli that it prefers relative to alternative stimuli that serve a similar biological function. From this perspective, the present data suggest that crushed barley is a "better" food than meat-meal, although factors other than preference obviously must be considered by farmers in selecting feed for their herds (see Duncan, 1978). The antilog of $\log q$ is not a felicity calculus, but it does indicate the relative value of particular foods in a given context. Even if highly preferred foods are not suitable as a primary ration, giving them occasionally as "treats" might improve the well-being of dairy cows without adding significantly to farmers' expenses or workload.

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APPENDIX A

Raw data for each cow for the last five sessions under each condition of Experiment 1. The schedules in effect under each condition are listed in Table 1, and the dependent variables are explained in the text.

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
1	1	78	79	528	387	158	137	9	9	24
1	1	57	61	509	319	200	180	8	9	19
1	1	62	83	388	417	222	184	10	10	25
1	1	79	80	484	348	188	190	11	11	23
1	1	63	85	413	420	234	194	10	9	26
1	2	93	53	529	258	202	217	10	9	18
1	2	81	52	468	299	191	252	9	8	19
1	2	87	60	515	303	159	234	8	9	19
1	2	92	44	558	201	169	282	9	8	15
1	2	104	53	545	231	194	237	9	10	19
1	3	95	68	519	274	118	296	6	11	40
1	3	97	53	628	241	117	221	5	8	30
1	3	93	46	645	175	118	270	6	10	32
1	3	76	47	477	250	147	331	7	10	30
1	3	89	70	467	290	139	316	8	12	32
1	4	111	85	796	415	227	372	9	14	51
1	4	118	74	924	336	171	376	7	14	45
1	4	117	86	863	406	215	335	9	13	49
1	4	115	89	804	427	266	406	10	16	49
1	4	104	104	768	443	239	361	9	15	56
1	5	87	85	523	333	100	253	5	12	48
1	5	78	91	490	357	94	267	4	12	47
1	5	77	70	560	292	61	298	3	11	38
1	5	78	83	494	337	99	284	5	12	40
1	5	106	91	566	309	54	272	3	12	44
1	6	141	63	908	291	211	393	11	13	42
1	6	132	75	901	294	244	372	12	13	46
1	6	125	73	827	355	261	382	12	12	44
1	6	147	76	876	285	259	389	13	13	46
1	6	144	66	938	234	288	352	13	11	40
1	7	90	86	691	312	135	676	6	27	41
1	7	72	67	524	236	249	705	10	30	30
1	7	92	89	691	287	189	644	8	28	49
1	7	96	77	647	325	212	647	8	25	42
1	7	110	97	662	269	145	738	7	32	48
1	8	37	51	198	103	82	672	4	35	16
1	8	35	59	252	179	150	648	6	33	23
1	8	47	68	296	189	96	535	5	31	24
1	8	34	71	373	151	165	1,012	16	49	16
1	8	29	46	194	113	99	608	3	30	15
1	9	89	60	608	280	204	122	9	6	39
1	9	91	65	599	303	206	104	9	5	42
1	9	108	57	688	269	199	53	10	3	37
1	9	101	69	585	280	226	121	11	6	38
1	9	95	70	584	315	204	104	10	5	42
1	10	105	58	610	270	232	91	11	4	36
1	10	102	45	681	201	237	92	12	4	29
1	10	110	33	747	194	192	70	9	3	26
1	10	98	43	596	178	291	139	12	5	25
1	10	114	31	675	159	262	117	10	4	24
1	11	165	57	1,168	272	254	113	14	5	42
1	11	179	63	1,180	283	277	65	13	2	42
1	11	154	75	977	354	351	131	14	5	56
1	11	163	66	1,080	255	408	71	16	3	40
1	11	155	64	940	274	471	123	16	4	44
1	12	118	73	799	335	339	330	15	15	42
1	12	130	89	734	420	357	308	13	14	57

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
1	12	115	83	667	432	456	260	14	13	54
1	12	142	72	863	374	352	229	12	10	54
1	12	126	63	1,124	275	254	185	10	10	36
1	13	92	31	555	130	360	165	17	6	28
1	13	88	32	486	142	450	140	21	6	30
1	13	70	38	418	170	468	153	20	7	25
1	13	70	30	415	123	512	153	18	6	24
1	13	70	38	346	200	503	162	22	7	28
1	14	106	79	643	371	516	303	20	13	50
1	14	121	72	736	349	429	296	18	15	48
1	14	120	67	767	317	464	276	21	12	44
1	14	110	68	725	330	421	334	18	13	45
1	14	120	73	723	361	436	304	21	12	49
2	1	52	48	473	370	170	203	7	9	17
2	1	55	50	489	361	209	148	9	8	15
2	1	55	54	521	415	125	145	8	8	17
2	1	64	58	516	362	167	160	10	9	18
2	1	63	61	492	408	213	233	11	11	22
2	2	102	37	591	207	167	243	8	9	18
2	2	67	55	510	297	183	217	8	7	19
2	2	75	44	460	242	249	258	10	9	19
2	2	66	34	623	193	170	222	7	9	17
2	2	76	43	552	251	215	193	8	7	18
2	3	44	24	632	159	230	184	8	7	19
2	3	92	32	694	165	116	229	5	9	27
2	3	67	45	471	238	187	309	8	11	36
2	3	65	36	583	194	111	321	5	10	32
2	3	49	36	483	238	228	261	7	9	28
2	4	64	44	626	199	123	261	5	9	31
2	4	56	44	484	215	181	324	7	11	28
2	4	59	43	515	280	136	276	7	10	35
2	4	65	48	505	275	163	262	7	11	34
2	4	69	37	603	215	123	262	5	9	33
2	5	53	64	399	420	99	288	5	12	42
2	5	59	56	465	335	127	274	4	11	42
2	5	61	58	470	341	76	320	3	12	46
2	5	67	54	505	323	79	302	3	11	43
2	5	57	49	517	299	104	291	4	10	38
2	6	104	46	986	263	263	298	12	11	42
2	6	96	51	801	296	323	395	15	14	42
2	6	107	67	835	390	255	360	14	15	53
2	6	102	52	925	277	255	352	13	14	42
2	6	93	57	804	357	290	358	14	13	42
2	7	55	48	653	208	157	806	6	20	34
2	7	77	57	771	207	249	663	6	25	42
2	7	79	64	656	255	215	688	8	28	44
2	7	69	61	618	253	241	700	9	27	42
2	7	70	52	651	195	211	756	7	24	42
2	8	22	49	214	139	68	662	3	30	17
2	8	40	54	294	170	38	606	2	31	26
2	8	32	50	289	122	70	654	3	34	18
2	8	25	46	173	113	145	590	5	30	16
2	8	27	71	269	464	132	952	4	29	26
2	9	83	41	614	254	248	99	11	4	34
2	9	72	46	510	280	288	128	12	6	32
2	9	89	42	599	282	232	99	11	5	38
2	9	83	43	526	295	292	95	12	4	38

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
2	9	85	48	552	291	255	119	11	5	40
2	10	83	37	626	262	269	71	12	3	31
2	10	83	37	567	227	321	97	12	4	33
2	10	87	38	627	284	208	114	8	4	34
2	10	64	30	509	205	388	102	10	4	26
2	10	84	39	632	237	310	115	11	4	36
2	11	133	39	1,005	284	464	54	18	2	38
2	11	126	30	942	235	592	36	19	1	29
2	11	128	44	1,039	299	396	75	16	3	42
2	11	138	40	1,069	274	353	112	14	4	42
2	11	111	43	921	339	457	97	17	4	39
2	12	93	58	721	320	396	373	13	14	47
2	12	97	58	685	332	423	376	13	13	48
2	12	120	43	842	214	412	359	12	12	50
2	12	117	37	875	184	451	298	11	11	43
2	12	92	38	779	167	490	384	14	13	36
2	13	70	21	375	84	554	193	23	7	19
2	13	80	25	443	115	500	152	21	6	21
2	13	84	30	418	141	514	137	21	6	26
2	13	59	32	304	197	535	166	21	6	24
2	13	80	29	439	131	473	162	19	7	24
2	14	103	57	621	320	581	288	22	11	45
2	14	106	48	703	223	500	383	18	13	47
2	14	120	64	725	331	433	322	16	12	61
2	14	99	53	648	286	560	335	19	12	44
2	14	108	42	757	203	476	382	18	12	46
3	1	107	114	481	269	188	271	9	11	19
3	1	123	125	516	319	148	226	9	11	22
3	1	139	139	494	406	146	168	11	10	19
3	1	145	191	447	487	133	145	9	10	20
3	1	100	114	372	380	256	199	11	9	19
3	2	139	44	640	215	172	178	7	7	14
3	2	117	58	571	229	191	218	8	8	15
3	2	130	81	526	288	183	210	9	9	17
3	2	150	48	648	177	208	200	9	9	15
3	2	188	63	666	154	173	217	8	8	15
3	3	165	57	681	163	174	188	7	9	25
3	3	211	65	632	154	128	289	6	10	30
3	3	204	38	700	94	228	185	9	7	19
3	3	193	26	942	73	49	141	2	6	17
3	3	160	61	720	157	165	163	7	7	24
3	4	177	41	759	148	147	154	5	6	24
3	4	145	38	791	76	80	256	4	8	18
3	4	159	49	813	166	46	182	4	7	14
3	4	185	66	713	161	10	223	14	9	25
3	4	162	46	827	140	90	146	3	6	17
3	5	191	106	527	283	109	284	5	12	40
3	5	175	97	567	273	76	293	4	11	35
3	5	158	85	465	284	106	351	4	11	31
3	5	181	94	572	231	91	320	4	11	33
3	5	235	92	573	278	96	260	4	10	30
3	6	248	67	868	233	329	381	12	13	36
3	6	249	71	895	220	340	356	14	11	41
3	6	257	61	963	241	278	321	12	11	38
3	6	261	91	929	293	235	356	10	12	44
3	6	251	102	795	332	293	391	13	14	43
3	7	197	62	815	218	179	598	7	21	45
3	7	174	67	820	186	200	623	7	23	37

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
3	7	145	62	788	184	282	559	7	18	42
3	7	193	55	936	190	77	604	3	19	40
3	7	211	60	972	176	108	552	5	20	33
3	8	52	46	185	72	161	797	5	30	14
3	8	66	68	215	101	203	821	5	33	17
3	8	96	67	471	148	252	832	6	33	22
3	8	108	89	394	157	267	979	7	37	26
3	8	74	71	295	90	116	80	3	30	26
3	9	274	39	722	140	230	114	9	4	34
3	9	246	46	655	139	154	151	1	16	28
3	9	249	34	729	145	233	126	8	5	28
3	9	201	47	724	151	282	67	9	4	20
3	9	212	60	672	219	349	140	11	6	30
3	10	234	41	719	169	237	82	8	4	25
3	10	219	16	790	108	179	127	7	4	18
3	10	235	24	741	107	274	84	9	3	22
3	10	209	27	632	112	394	91	11	3	26
3	10	212	40	675	156	300	131	10	3	28
3	11	377	40	1,231	198	355	26	14	2	39
3	11	315	45	1,112	192	378	124	16	5	34
3	11	360	33	1,152	175	393	86	14	3	33
3	11	353	14	1,238	66	454	46	18	2	16
3	11	355	31	1,210	171	395	38	14	2	35
3	12	257	75	798	200	454	361	13	13	44
3	12	307	83	901	295	371	247	12	12	49
3	12	240	69	767	250	474	320	13	13	40
3	12	248	82	767	255	387	423	12	12	43
3	12	240	41	1,129	157	299	224	10	8	29
3	13	119	28	385	77	583	162	19	6	17
3	13	122	35	301	94	632	179	21	8	25
3	13	65	22	227	46	697	236	20	7	15
3	13	108	24	394	76	534	205	19	7	20
3	13	106	24	395	63	569	179	21	7	14
3	14	185	66	708	214	534	354	16	11	36
3	14	245	57	751	180	543	337	18	11	33
3	14	202	60	675	139	609	386	17	12	29
3	14	190	58	646	173	614	382	17	10	34
3	14	230	59	713	159	640	301	19	10	33
4	1	119	95	464	455	124	162	11	9	17
4	1	110	92	441	477	143	145	9	10	15
4	1	108	126	395	531	146	138	9	10	22
4	1	90	111	411	536	108	151	9	10	20
4	1	95	112	420	567	98	140	10	10	17
4	2	80	75	530	358	81	236	7	9	14
4	2	120	68	555	289	109	256	9	10	14
4	2	125	60	616	287	88	214	7	9	13
4	2	113	59	635	257	90	226	9	8	11
4	2	111	58	583	256	156	212	10	8	13
4	3	120	60	554	295	80	278	7	9	25
4	3	99	56	569	285	93	259	5	9	24
4	3	116	57	744	204	68	190	6	8	19
4	3	131	67	686	259	75	183	6	10	22
4	3	126	51	750	190	91	174	7	8	20
4	4	100	53	600	252	96	256	5	10	21
4	4	110	66	554	320	107	225	5	10	25
4	4	110	62	533	314	76	281	5	11	22
4	4	114	73	569	371	63	204	5	10	27
4	4	89	48	610	259	110	231	6	8	21

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
4	5	112	77	462	431	99	276	3	11	27
4	5	98	75	550	377	91	307	5	12	27
4	5	70	61	372	394	56	385	4	12	24
4	5	82	59	516	341	78	278	5	9	27
4	5	82	62	476	339	55	349	4	12	26
4	6	117	33	1,025	265	235	289	11	10	16
4	6	155	42	1,171	240	152	265	9	10	20
4	6	139	49	1,166	277	160	287	10	10	25
4	6	142	46	1,118	256	164	214	10	12	24
4	6	132	50	1,061	261	168	316	12	11	23
4	7	70	57	682	339	134	675	7	24	24
4	7	70	64	773	315	170	578	8	22	26
4	7	76	75	703	339	176	594	9	25	27
4	7	74	65	716	282	135	675	6	25	25
4	7	71	54	788	291	180	549	8	17	22
4	8	27	43	276	10	73	798	4	30	11
4	8	39	46	492	134	117	862	6	32	12
4	8	42	60	496	268	103	937	5	35	14
4	8	38	45	698	143	438	934	3	3	9
4	8	20	48	294	126	889	954	3	5	7
4	9	96	29	764	182	111	152	6	6	16
4	9	70	26	732	192	157	122	8	5	13
4	9	91	25	758	151	173	124	9	5	12
4	9	95	21	914	92	141	81	8	3	12
4	9	110	38	738	209	126	132	7	5	18
4	10	97	23	800	128	219	59	12	2	13
4	10	114	28	788	170	186	64	10	3	14
4	10	92	11	838	89	196	81	10	3	8
4	10	122	11	956	121	55	69	3	2	7
4	10	112	13	934	99	167	94	10	3	8
4	11	162	29	1,274	160	261	117	15	3	16
4	11	180	22	1,309	151	265	80	15	3	14
4	11	173	16	1,317	97	333	56	17	2	12
4	11	177	21	1,206	159	384	58	17	2	16
4	11	168	24	1,333	115	330	28	17	1	20
4	12	120	63	750	329	343	388	13	13	31
4	12	130	65	853	298	352	323	14	12	30
4	12	127	54	1,057	284	203	282	11	11	32
4	12	96	26	1,334	198	139	157	6	7	16
4	12	138	52	944	253	355	255	12	12	27
4	13	62	23	480	131	460	133	18	6	14
4	13	50	18	435	76	513	180	16	6	10
4	13	72	17	636	141	307	119	12	4	12
4	13	48	14	563	103	402	135	15	5	8
4	13	67	21	579	124	350	151	16	6	14
4	14	112	43	876	217	432	281	15	11	25
4	14	127	43	868	251	424	262	18	11	25
4	14	124	47	870	238	441	259	17	11	25
4	14	95	34	867	194	486	263	18	9	20
4	14	134	40	906	225	389	286	17	10	29
5	1	83	79	420	417	164	206	10	10	21
5	1	63	67	456	596	68	85	7	6	11
5	1	107	88	501	438	109	160	11	11	21
5	1	84	89	364	442	168	231	10	10	20
5	1	72	79	377	435	166	267	10	12	21
5	2	89	81	549	340	145	172	7	7	17
5	2	74	49	600	226	183	208	9	8	16
5	2	89	69	532	273	174	226	9	9	17
5	2	87	61	503	279	190	234	8	9	17

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
5	2	92	51	638	298	124	162	9	9	19
5	3	106	52	534	309	154	210	9	8	38
5	3	109	72	576	356	151	121	7	8	33
5	3	119	46	615	285	142	161	5	7	19
5	3	118	65	522	343	153	196	8	10	32
5	3	119	54	639	270	157	141	6	9	25
5	4	180	77	735	388	299	386	8	14	36
5	4	174	47	722	323	343	421	8	11	30
5	4	160	56	651	362	300	514	7	14	29
5	4	207	63	904	344	258	391	7	13	44
5	4	182	55	823	310	297	422	8	14	33
5	5	106	63	407	266	106	427	3	11	25
5	5	143	83	515	306	125	262	4	12	35
5	5	96	58	381	290	162	381	5	10	24
5	5	127	85	487	369	82	306	3	11	37
5	5	85	46	367	248	188	401	5	10	22
5	6	165	38	816	244	414	330	11	9	31
5	6	171	48	788	273	433	396	11	11	31
5	6	167	79	757	381	359	297	10	13	33
5	6	198	78	891	308	352	263	10	9	34
5	6	174	55	908	276	346	296	10	11	34
5	7	69	76	548	358	366	539	8	22	34
5	7	75	59	891	214	336	371	6	16	24
5	7	87	58	539	212	229	828	6	24	28
5	7	125	79	729	242	219	617	6	23	28
5	7	91	49	508	248	340	711	9	21	22
5	8	62	57	285	236	177	688	5	32	19
5	8	69	63	316	288	192	591	6	32	12
5	8	43	69	271	288	216	742	5	38	17
5	8	37	53	233	214	252	852	5	30	11
5	8	21	46	95	140	147	708	3	30	7
5	9	143	27	712	232	405	79	15	4	20
5	9	110	35	537	267	312	89	10	4	18
5	9	120	34	560	247	293	108	8	5	19
5	9	138	27	635	198	256	114	7	5	20
5	9	142	38	646	223	285	53	9	4	18
5	10	135	20	628	196	328	52	10	2	22
5	10	130	29	654	242	224	85	8	3	21
5	10	121	26	626	193	292	101	9	4	18
5	10	108	18	624	190	347	81	11	3	12
5	10	126	16	643	160	315	84	8	3	16
5	11	172	30	1,017	260	397	131	16	3	24
5	11	228	56	1,006	367	358	79	14	5	36
5	11	208	22	1,003	209	486	106	15	3	19
5	11	222	43	1,079	308	345	96	12	5	30
5	11	230	48	1,033	283	408	89	14	4	32
5	12	165	53	799	392	344	270	12	9	32
5	12	157	53	671	445	389	311	12	11	35
5	12	181	69	832	324	404	249	12	12	40
5	12	136	48	752	346	419	308	12	11	26
5	12	162	69	767	479	361	202	11	11	30
5	13	88	19	456	134	407	207	14	5	16
5	13	66	16	388	79	464	274	12	6	13
5	13	67	12	482	101	522	106	14	3	10
5	13	88	17	557	144	420	104	13	5	12
5	13	79	13	440	62	490	210	16	5	10
5	14	138	39	569	313	576	349	14	9	22
5	14	167	45	649	332	493	328	16	10	28

APPENDIX A

(Continued)

Cow	Condi- tion	Responses		Net time (s)		PRP time (s)		Reinforcers		Total change- overs
		Left	Right	Left	Right	Left	Right	Left	Right	
5	14	150	30	658	222	543	381	14	11	20
5	14	168	45	690	263	502	354	17	11	27
5	14	186	42	691	256	465	398	15	11	30

APPENDIX B

Raw data for each cow for the last five sessions under each condition of Experiment 2. The schedules in effect under each condition are listed in Table 2, and the dependent variables are explained in the text.

Cow	Condi- tion	Responses		Total time (s)		Time (s) in other behavior		Reinforcers	
		Left	Right	Left	Right	Left	Right	Left	Right
4	1	63	58	438	766	338	652	7	6
4	1	100	96	610	585	403	405	10	9
4	1	117	101	640	548	427	375	9	10
4	1	116	105	647	544	399	355	10	10
4	1	113	107	681	497	471	323	11	7
4	2	94	59	778	414	627	315	14	7
4	2	117	76	769	465	613	364	15	8
4	2	102	63	861	362	712	270	14	6
4	2	67	42	666	544	589	460	12	7
4	2	76	53	762	431	672	350	13	6
4	3	91	105	584	615	423	463	9	13
4	3	86	112	589	605	439	438	9	14
4	3	63	75	548	544	416	414	7	12
4	3	95	104	578	611	433	457	9	16
4	3	70	99	515	670	329	471	4	14
4	4	109	42	841	335	702	261	24	5
4	4	103	44	888	317	786	234	28	3
4	4	98	34	901	304	770	261	26	5
4	4	94	44	877	300	766	215	27	5
4	4	96	44	842	361	735	283	25	5
4	5	60	141	372	811	232	648	4	28
4	5	59	124	327	857	194	681	5	27
4	5	68	125	371	825	239	645	4	25
4	5	49	100	337	843	259	687	4	26
4	5	53	116	413	825	338	640	6	26
5	1	175	236	615	568	352	282	11	10
5	1	166	221	611	584	392	298	12	11
5	1	74	111	294	267	157	96	5	6
5	1	148	223	616	553	388	282	10	12
5	1	139	217	648	521	433	243	11	11
5	2	211	145	766	420	423	170	15	8
5	2	155	121	779	412	547	228	17	7
5	2	143	140	695	513	529	264	16	8
5	2	182	128	776	420	522	202	16	8
5	2	155	141	757	446	469	246	18	9
5	3	102	219	524	650	279	356	8	16
5	3	102	216	544	634	334	330	6	17
5	3	75	207	607	594	419	287	8	13
5	3	91	227	423	784	201	367	7	15
5	3	69	227	401	814	257	484	9	17

APPENDIX B

(Continued)

Cow	Condi- tion	Responses		Total time (s)		Time (s) in other behavior		Reinforcers	
		Left	Right	Left	Right	Left	Right	Left	Right
5	4	170	93	865	336	629	196	27	5
5	4	160	101	890	336	694	212	28	5
5	4	152	90	826	351	643	211	27	6
5	4	165	104	912	294	717	172	28	6
5	4	153	71	900	284	723	180	29	5
5	5	69	225	369	803	262	552	6	28
5	5	72	248	346	821	243	533	8	30
5	5	73	238	388	898	287	538	7	29
5	5	70	258	330	858	224	575	4	32
5	5	54	203	337	915	241	679	5	33
6	1	59	47	643	547	395	305	9	7
6	1	63	60	602	584	369	345	11	9
6	1	66	52	591	586	286	274	9	10
6	1	70	44	652	539	316	260	8	7
6	1	63	52	615	566	367	289	11	10
6	2	67	43	658	528	450	358	13	9
6	2	69	55	580	622	404	338	16	6
6	2	57	42	700	479	535	303	12	6
6	2	64	56	637	573	400	291	14	5
6	2	64	36	776	445	530	276	13	6
6	3	38	42	506	690	295	531	7	12
6	3	33	49	423	762	282	601	7	15
6	3	34	46	452	733	296	570	6	13
6	3	46	61	419	775	224	524	7	14
6	3	50	55	426	762	241	542	8	16
6	4	66	41	703	478	454	231	24	6
6	4	56	34	839	346	670	142	26	4
6	4	59	28	900	298	695	152	25	4
6	4	60	28	916	259	696	125	23	2
6	4	48	25	919	278	761	148	24	4
6	5	27	46	279	913	146	814	4	24
6	5	27	46	305	909	192	756	4	23
6	5	24	46	302	902	208	775	5	21
6	5	31	61	296	896	176	705	5	23
6	5	20	49	285	926	203	814	5	25
7	1	195	90	714	483	257	234	11	8
7	1	102	67	610	587	317	303	11	10
7	1	89	72	625	547	301	298	11	10
7	1	120	77	609	591	288	311	11	12
7	1	112	81	636	591	262	272	10	11
7	2	160	71	722	441	374	247	15	8
7	2	116	70	706	471	377	230	16	6
7	2	187	72	755	438	404	238	17	8
7	2	136	78	670	524	380	336	16	8
7	2	147	86	729	476	378	255	16	8
7	3	151	91	570	625	198	322	6	14
7	3	137	81	593	596	274	397	7	14
7	3	119	73	568	634	256	405	7	15
7	3	159	68	651	540	254	353	8	16
7	3	199	89	614	572	237	337	6	15
7	4	224	47	892	278	565	157	31	5
7	4	208	46	890	277	595	138	30	5
7	4	251	52	911	270	597	160	31	5
7	4	229	47	900	278	607	132	31	5
7	4	235	65	886	291	592	120	32	4
7	5	189	85	446	747	213	563	5	29
7	5	196	85	422	813	192	565	6	30
7	5	198	79	404	774	137	567	3	28

APPENDIX B

(Continued)

Cow	Condi- tion	Responses		Total time (s)		Time (s) in other behavior		Reinforcers	
		Left	Right	Left	Right	Left	Right	Left	Right
7	5	215	77	437	766	146	561	5	28
7	5	122	60	399	819	210	649	5	28

APPENDIX C

Raw data for the last five sessions of Experiment 2.

Cow	Condi- tion	Time (s) in chewing		Time (s) in picking or licking		Time (s) in other behavior		Net time (s) in responding	
		Left	Right	Left	Right	Left	Right	Left	Right
4	1	117	139	167	160	54	353	100	114
4	1	147	150	211	209	45	46	207	180
4	1	164	110	213	231	50	34	213	173
4	1	142	124	219	187	38	44	248	189
4	1	148	92	302	200	21	31	210	174
4	2	239	116	377	169	11	30	151	99
4	2	257	143	331	197	25	24	156	101
4	2	227	63	447	163	38	44	149	92
4	2	246	170	321	230	22	60	77	84
4	2	255	94	304	189	113	67	90	81
4	3	140	156	234	224	49	83	161	152
4	3	149	135	250	216	40	87	150	167
4	3	136	122	229	264	51	28	132	130
4	3	125	141	277	249	31	67	145	154
4	3	83	146	140	258	106	67	186	199
4	4	199	60	455	146	48	55	139	74
4	4	291	83	467	114	28	37	102	83
4	4	275	85	480	142	15	34	131	43
4	4	263	52	405	131	98	32	111	85
4	4	248	47	393	173	94	63	107	78
4	5	86	245	118	367	28	36	140	163
4	5	95	284	92	383	7	14	133	176
4	5	75	231	128	396	36	18	132	180
4	5	79	280	153	372	27	35	78	156
4	5	99	239	204	372	35	29	75	185
5	1	69	59	262	216	21	7	263	286
5	1	64	84	299	199	29	15	219	286
5	1	47	25	82	57	28	14	137	171
5	1	83	98	253	157	52	27	228	271
5	1	111	59	279	166	43	18	215	278
5	2	88	54	324	112	11	4	343	250
5	2	82	39	428	182	37	7	232	184
5	2	84	52	415	203	30	9	166	249
5	2	76	30	423	169	23	3	254	218
5	2	86	50	361	181	22	15	288	200
5	3	64	114	204	242	11	0	245	294
5	3	49	100	269	230	16	0	210	304
5	3	64	55	354	230	1	2	188	307
5	3	34	50	149	292	18	25	222	417
5	3	52	90	200	313	5	81	144	330
5	4	179	17	441	176	9	3	236	140
5	4	185	22	497	183	12	7	196	124
5	4	156	32	468	169	19	10	183	140

APPENDIX C

(Continued)

Cow	Condi- tion	Time (s) in chewing		Time (s) in picking or licking		Time (s) in other behavior		Net time (s) in responding	
		Left	Right	Left	Right	Left	Right	Left	Right
5	4	140	8	577	162	0	2	195	122
5	4	191	18	530	162	2	0	177	104
5	5	52	186	206	349	4	17	107	251
5	5	65	157	174	363	4	13	103	288
5	5	52	158	235	364	0	16	101	360
5	5	35	218	174	343	15	14	106	283
5	5	37	248	199	421	5	10	96	236
6	1	167	135	221	145	7	25	248	242
6	1	175	165	191	180	3	0	233	239
6	1	88	128	193	134	5	12	305	312
6	1	135	118	146	142	35	0	336	270
6	1	199	147	166	142	2	0	248	277
6	2	147	123	269	218	34	17	208	170
6	2	191	127	209	188	4	23	176	284
6	2	169	127	300	133	66	43	165	176
6	2	138	95	260	152	2	44	237	282
6	2	196	98	334	178	0	0	246	169
6	3	123	209	132	281	40	41	211	159
6	3	87	241	168	350	27	10	141	161
6	3	113	302	183	247	0	21	156	163
6	3	104	214	120	303	0	7	195	251
6	3	101	274	137	232	3	36	185	220
6	4	178	98	276	133	0	0	249	247
6	4	247	46	423	95	0	1	169	204
6	4	230	57	461	95	4	0	205	146
6	4	265	48	411	77	20	0	220	134
6	4	228	60	393	88	140	0	158	130
6	5	61	343	85	453	0	18	133	99
6	5	77	321	115	435	0	0	113	153
6	5	74	288	134	483	0	4	94	127
6	5	64	241	104	455	8	9	120	191
6	5	65	342	119	461	19	11	82	112
7	1	138	104	75	106	44	24	457	249
7	1	179	134	74	126	64	43	293	284
7	1	170	137	73	136	58	25	324	249
7	1	164	155	80	130	44	26	321	280
7	1	144	130	84	116	34	26	374	319
7	2	180	119	142	109	52	19	348	194
7	2	212	87	133	90	32	53	329	241
7	2	218	121	127	98	59	19	351	200
7	2	205	116	109	106	66	114	290	188
7	2	195	105	122	114	61	36	351	221
7	3	91	179	52	96	55	47	372	303
7	3	130	206	68	162	76	29	319	199
7	3	109	219	75	168	72	18	312	229
7	3	119	196	70	147	65	10	397	187
7	3	98	195	61	118	78	24	377	235
7	4	348	99	183	54	34	4	327	121
7	4	371	78	179	47	45	13	295	139
7	4	365	88	202	63	30	9	314	110
7	4	382	79	196	50	29	3	293	146
7	4	382	65	185	51	25	4	294	171
7	5	91	364	79	166	43	33	233	184
7	5	97	285	60	266	35	14	230	248
7	5	49	340	45	187	43	40	267	207
7	5	77	333	44	218	25	10	291	205
7	5	75	310	89	271	46	68	189	170