TIME-BASED AND COUNT-BASED MEASUREMENT OF PREFERENCE¹

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Rats' pressing on two levers was reinforced according to two independent variable-interval schedules that were varied during the experiment. Since the levers were connected directly to the programming equipment, bypassing the standard pulseformers, reinforcement could occur while a lever was held down. Although the time a lever was pressed might, therefore, have varied independently of number of presses, these two measures covaried substantially, because the average duration of the presses remained roughly constant. This rough invariance may have resulted from the rats' tendency to make bursts of brief presses (*i.e.*, to jiggle the levers), even though the contingencies encouraged holding. When duration did vary, presses on the two levers tended to vary together. As a result, relative time spent pressing corresponded closely to relative number of presses. Both of these measures conformed well to the matching law. Absolute behavioral frequency at a lever, measured either way, varied directly with proportion of reinforcement for that lever, in accordance with the generalized version of the matching law. Number of presses seemed, on balance, to be a slightly more reliable measure than pressing time. The substantial interchangeability may prove more significant than the slight disparity, however, because it supports the notion that all behavior can be measured on a common scale of time.

Key words: measurement of preference, time allocation, matching law, choice, concurrent variable-interval schedules, rate of changeover, changeover delay, lever pressing, rats

For a situation with n independent alternative activities, the matching law states that for any one of them:

$$\frac{B_i}{\sum_{i=1}^n B_i} = \frac{r_i}{\sum_{i=1}^n r_i} \quad (1)$$

where B_i is the frequency of Activity i and r_i is the reinforcement obtained from Activity i . Herrnstein (1974) pointed out that the summation in the left-hand denominator of Equation 1 requires that the frequencies of all the various activities be measured on a common scale. To add or compare the frequency of pecking to the frequency of scratching, one must either convert the units of one to the units of the other or measure both on some common scale.

Premack (1965, 1971) and Baum and Rachlin (1969) suggested that the common scale could be time spent in an activity. Studies of continuous activities, such as standing in a location or holding a button, support the notion that the matching law is a law of time allocation (Baum, 1973, 1975; Baum and Rachlin, 1969; Brownstein, 1971; Brownstein and Pliskoff, 1968).

Although the activities in these studies lent themselves to measuring the time spent in them, most studies have measured frequency in terms of counts of responses. Activities such as key pecking or lever pressing may be most conveniently measured by counting instances. Premack (1965) and Baum and Rachlin (1969) pointed out, however, that counting instances sacrifices no information as long as each instance takes up approximately the same amount of time. To convert number of pecks or presses to time pecking or pressing, for example, one would multiply by the time per press or peck.

Although some evidence (*e.g.*, Blough, 1963; Findley, 1954) suggests that interresponse time tends to remain invariant during periods of key pecking or lever pressing, little attempt has

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been made to study the constancy of the duration of pecks or presses.

The present experiment had two purposes. First, both number of presses and duration of pressing were measured to ask whether they might be interchangeable. To minimize constraint on the variability of duration, the standard practice of interposing a pulseformer between lever and programming equipment was omitted. Whereas the pulseformer arranges reinforcement for brief responses, because only the initiation of a press can produce reinforcement, connecting the lever directly to the programming equipment, as in this experiment, allows lever holding to be reinforced.

The second purpose was to provide the first published set of data on rats exposed to a variety of concurrent variable-interval schedules. Several sets are available for pigeons, at least two for humans (Baum, 1975; Schroeder and Holland, 1969), and one for monkeys (Iglauder and Woods, 1974). The only previous experiment with rats employed two pairs of schedules, of which individual rats were exposed to only one (Shull and Pliskoff, 1967).

METHOD

Subjects

Five male brown rats, bred in the Harvard Psychological Laboratories, were maintained at 80% of their free-feeding body weights. They were approximately 1-yr old at the start of the experiment. All had been previously trained to press a lever with a pulseformer. Rat 6 died of a respiratory infection during the final condition of the experiment.

Apparatus

The experimental chamber, 22 cm by 26 cm by 20 cm high, conformed to the standard design for rats. One side wall and the ceiling were made of transparent plastic; the other side wall and the front and back walls were aluminum. The floor consisted of 6-mm wide stainless-steel rods, 2 cm apart. On the front wall were mounted two response levers, extending 2 cm into the chamber, 11 cm apart (edge to edge), 4.5 cm wide, 8 cm from the floor, requiring a downward excursion of 2 mm and a force equivalent to 18 g (0.18 N) to operate. Pressing a lever opened a pair of relay contacts. (This permits briefer presses than the snap-action of a microswitch.) Six cm

above each lever, a circular white translucent plastic disk, 32 cm in diameter, could be trans-illuminated with two white 7-W ac bulbs. A solenoid-operated dipper, containing approximately 0.1 ml of sweetened condensed milk diluted with an equal volume of water, could be raised to an opening at the level of the floor, 15 mm from the front wall, midway between the levers. Two 6-W ac houselights were mounted on the outside of the ceiling above one side of the chamber. A light-proof sound-attenuating box enclosed the chamber. White noise from a speaker in the box helped to mask extraneous sounds.

Electromechanical equipment in an adjoining room controlled and recorded events in the chamber. Conventional pulseformers were used only to count presses. Standard running-time meters recorded pressing time.

Procedure

The reinforcer, 4.3 sec operation of the dipper, was scheduled by two independent concurrent variable-interval (VI) schedules—one for each lever. Contrary to usual practice, which requires a lever press to be initiated at or after the moment of scheduling a reinforcer, reinforcement occurred whenever a lever was depressed and a reinforcer was scheduled for that lever. This meant that if a rat held a lever depressed, reinforcement occurred immediately a reinforcer was scheduled for the lever. The difference from usual procedure reflects simply the bypassing of the pulseformer that customarily standardizes the electrical pulses produced by lever presses: each lever operated its reinforcer-scheduling circuit directly.

Since the rats were already trained, they were put immediately into the first experimental condition. Only one feature, the changeover delay (COD), which prevented reinforcement for a period after switching from pressing one lever to pressing the other, was introduced gradually. Initially 2 sec, it was increased over four weeks to 7.5 sec, where it remained for the rest of the experiment. The results of Shull and Pliskoff (1967) suggested that this particular value would be the shortest at which performance might conform to the matching relation.

Table 1 shows the order of experimental conditions and the number of sessions each lasted. All VI schedules contained 14 intervals

drawn from the progression suggested by Fleshler and Hoffman (1962).

The houselights were lit before and after a session, but were off during the session. As long as a lever was depressed, the light above it was lit. Sessions ended after the sixtieth reinforcer, except as noted in Table 1, and were conducted daily, except for holidays. Experimental conditions continued until at least four rats' performances appeared stable for at least seven days, except for the last condition, as noted in Table 1.

Table 1

Order of experimental conditions and number of sessions of exposure.

Schedule		Number of Sessions
Left (minutes)	Right	
VI 2	VI 2	36
VI 1	VI 2	30
VI 0.5	VI 2	38
VI 0.75	VI 2	31
VI 1	VI 2	43*
VI 1.5	VI 2	47
VI 2	VI 2	36**
VI 2	VI 1	51
VI 2	VI 0.5	44
Extinction	VI 0.5	10
VI 2	VI 0.5	47
VI 2	VI 1	33
VI 2	VI 2	32***

*Rat 4 given 3 hr of extinction on left, 50 reinforcements for the right lever.

**50 reinforcers per session.

***Rat 6 died, Rat 2 received 14 sessions, and Rat 4 received 45 sessions.

RESULTS

The data were summarized as follows. Graphs displaying relative number of presses and relative time pressing were examined to estimate, for each rat in each condition, the maximum number of sessions over which performance could be considered stable. The counts and times were summed over these sessions. The number of sessions used ranged from three to 31, with an average of 11. Small numbers were used in general for strong preferences with little day-to-day variation in performance, whereas larger numbers were used when day-to-day performance was more variable. Although this technique may render the sample sizes used to estimate stable performance unequal, it produces more reliable esti-

mates of central tendency, because the larger samples compensate for greater variability. The summed raw data, used in the following analysis, are available in tabular form from the author.

Figure 1 shows behavioral frequency, measured as presses per minute (circles) and proportion of time spent pressing (triangles), as a function of proportion of reinforcement obtained.

The left-hand graphs show frequency for the left lever; the right-hand graphs for the right lever. The filled symbols indicate conditions in which the lever's associated schedule was VI 2-min, and the other schedule varied. The open symbols indicate conditions in which the lever's associated schedule varied and differed from VI 2-min.

With the exception of some possibly aberrant conditions, primarily among the first and second, behavioral frequency conformed approximately to a negatively accelerated function of proportion of reinforcement. In agreement with previous research on pigeons, behavioral frequency of each alternative varied directly with reinforcement for that alternative (open symbols), and inversely with reinforcement for the other alternative (filled symbols; Catania, 1963; McSweeney, 1975).

Figure 1 suggests a high degree of correspondence between presses per minute and proportion of time pressing. This was confirmed by considering proportion of time as a function of rate of pressing, and fitting least-squares lines of regression in logarithmic coordinates. If the time measure was directly proportional to the count measure, the slope of the regression line should equal 1.0. For the left lever, slopes for individual rats ranged from 0.84 to 1.11, with an average of 1.00, and the line for the rats' data pooled had a slope of 1.03 and accounted for 94% of the variance. For the right lever, in contrast, individual rats' slopes were more variable (range: 0.42 to 1.40; average: 0.90), and the line for the pooled data had a slope of 0.82. A line of slope 1.0 accounted for only 73% of the variance. Although time and number appeared to be equivalent for presses on the left lever, such an assumption might be inaccurate for presses on the right lever.

It is still possible that time per press remained constant enough to render time and number roughly equivalent. Figure 2 shows

Fig. 1. Observed absolute response rate (circles) and proportion of session time pressing (triangles) as a function of proportion of obtained reinforcement. Filled symbols indicate conditions in which that lever was associated with a VI 2-min schedule. Points labelled "1" and "2" represent data from the first and second conditions. The points labelled "a" in Rat 1's graphs are from a condition that was considered aberrant.

time per press (time spent pressing divided by number of presses) as a function of the proportion of reinforcers obtained from the left lever. Each condition produced a pair of points, except two for Rat 4 in which no presses occurred on the right lever. Although the duration of presses varied across conditions, no consistent pattern of variation appears across rats. Although the durations of left and right presses tended generally to vary together, close examination reveals that, on the whole, presses on the left lever (open circles) varied less than presses on the right (filled circles).

Figure 2 reveals that, although the rats were rewarded for holding the levers, still they tended to make brief presses. In few conditions did any average duration exceed 0.5 sec, and in no condition did any average duration come up to 1 sec. Such brevity of response might be expected to decrease the reliability of pressing time relative to number of presses.

Fig. 2. Average press duration (logarithmic scale) as a function of proportion of reinforcement obtained by pressing the left lever. Each point represents data for one lever in one condition.

The tendency of press durations on the two levers to vary together suggests that *relative* pressing time might be more generally interchangeable with *relative* number of presses than absolute time was with absolute number. This was confirmed by considering the ratio of pressing time left to pressing time right as a function of the ratio of presses left to presses right in logarithmic coordinates. For every rat, a least-squares regression line fitted with a slope of 1.0 (*i.e.*, direct proportionality) accounted for over 90% of the variance. The constant of proportionality varied to both sides of 1.0, the value that would make the two ratios equal. It ranged from 0.78 (Rat 1) to 1.15 (Rat 3).

Although this suggests that there might be little basis for judging presses or time a more reliable measure, the correspondence between relative time and relative presses was imperfect enough that one measure could have matched relative reinforcement better than the other.

Figure 3 compares the two measures' conformity to the matching law. It shows the ratio of presses (P_1/P_2 ; circles) and the ratio of times (T_1/T_2 ; triangles) as functions of the ratio of reinforcement (r_1/r_2) in logarithmic coordinates. Alternate rats' data points are filled for readability. The lines, each of which has a slope of 1.0 and passes through the point (1,1), represent the matching relation. Since in these coordinates any constant bias in favor of one level should only shift the data points up or down a constant distance, conformity to the matching relation consists in the points' paralleling the line, rather than necessarily falling on it (see Baum, 1974b, for further explanation). The parameter e gives, for each set of points, the proportion of variance unaccounted for by a line of slope 1.0. Whereas with Rats 1, 2, and 3 this error measure approached equality for presses and time, with Rats 4 and 6 it was substantially higher for time than presses.

Previous research on concurrent performance has revealed that rate of changeover between alternatives generally varies inversely with degree of disparity between the alternatives (Baum, 1973, 1974a, 1975; Brownstein and Pliskoff, 1968; Herrnstein, 1961; Schroeder and Holland, 1969; Shull and Pliskoff, 1967; Stubbs and Pliskoff, 1969). Those situations that generate stronger preferences, because of

Fig. 3. Ratio of pressing time (right column; triangles) left (T_1) to right (T_2) and ratio of number of presses (left column; circles) left (P_1) to right (P_2) as a function of the ratio of reinforcement obtained from the left (r_1) and right (r_2) levers, in logarithmic coordinates. A line indicates the locus of equality—i.e., the matching relation. Alternate rats' symbols are filled for readability.

greater difference between alternatives, generate also lower rates of changeover. The highest rates of changeover occur when the organism is indifferent between alternatives (Baum, 1973, 1974a, 1975).

Figure 4 shows that the relation typical of previous research held also in the present study. The logarithm of the rate of changeover was approximately linearly related to the logarithm of the ratio of presses, with the highest rates at indifference (ratio of 1.0). The same relation was apparent when the rates of changeover were graphed as a function of the ratios of time. There was a general tendency toward lower rates of changeover for preferences favoring the left lever (filled circles).

Fig. 4. Rate of changeover as a function of ratio of presses, in logarithmic coordinates. Filled and open circles represent conditions in which the left and right levers, respectively, were preferred. The point labelled "a" represents the same aberrant condition noted in Figure 1.

In contrast to some similar data gathered with pigeons (Baum, 1973, 1974a), the rates of changeover in Figure 4 appeared as orderly or more orderly when graphed as a function of the reinforcement ratios, rather than the behavior ratios. That is, the points as closely or more closely approximated a straight line, and the tendency for filled and open points to separate was absent. The improvement was particularly clear for the data for Rat 6. Preference was used as the abscissa of Figure 4, nevertheless, because this permitted inclusion of data from conditions in which all reinforcement was obtained from only one of the alternatives, but preference was not exclusive.

DISCUSSION

On the whole, Figures 1, 3, and 4 corroborate the results of previous research with pigeons, monkeys, and humans, and support Equation 1. More detailed analyses may be obtained from the author.

Logically, the comparison between time and response measures could have turned out three ways: one or the other measure could have proven more reliable (*i.e.*, conformed better to the matching relation), or the two could have proven equally reliable. On balance, the present data might be said to favor slightly presses over time. One would conclude this from the generally closer fits (smaller values of e) in Figure 3. On the other hand, the lack of any striking difference in reliability may be more significant than the overall impression of a slight difference. The absence of large or systematic variations in press duration (Figure 2) produced substantial, albeit imperfect, covariance between number of presses and time pressing. The principal deviations from this covariance were confined to the data of one rat (Rat 6). Future research may reveal that such covariance is the rule, rather than the exception.

If covariation were the exception, the present results would lie at one end of a continuum from weak to strong covariation. One might argue that the continuum of results would represent only the duration of the responses studied, because brevity alone might ensure invariant duration. For example, there must be a limit on how fast a rat can press and let go of a lever. If presses are brief, their duration can vary only between the necessary

minimum and the upper limit imposed by the rats' manner of pressing. One would then expect that results at other points on the continuum, being less constrained in response duration, would favor either response rate or time spent responding as a more reliable measure. Whether or not such a view proved correct, one would still wish to know why the rats produced the brief and invariant responses that led to the observed covariation.

If, on the other hand, equal reliability (*i.e.*, covariation) of time spent responding and number of responses were the rule, one would reverse the above reasoning. Covariation of the measures implies invariant duration of individual responses. As explained in the introduction, such a constant time quantum allows number of responses to be rescaled as time spent responding. The finding of covariation, therefore, supports the notion that all behavior can be measured on the common scale of time.

One may explain the brevity of response (Figure 2) in at least three ways. The rats' early experience with the standard lever-pulse-former combination offers the simplest explanation. The effects of prior differential reinforcement inherent in their early training might have persisted through the 16 months of the experiment. Other rats, however, trained from the start without a pulseformer, develop similarly brief responses. Figure 5 shows frequency distributions of press durations of three such rats from the last three days of training on a VI 80-sec schedule. They began training with a VI 20-sec schedule, then received 28 sessions of training on the VI 80-sec schedule. Each frequency distribution shows a strong mode at a duration of about 0.5 sec. Durations longer than 1.5 sec conformed approximately to an exponential distribution (a straight line in the coordinates of Figure 5). Although presses tended systematically to be short, the linear segment indicates that longer presses tended to be terminated randomly. The use of only one lever, and one that operated a microswitch, may account for the average durations' (0.67, 1.49, 1.54 sec) exceeding slightly those in Figure 2. Figure 5 shows, nevertheless, that training without a pulseformer suffices to produce and maintain brief presses.

As a second explanation, therefore, it seems possible that the conditions somehow differen-

tially reinforced brief presses. Since a rat had to let go of the lever to eat the reinforcer, presses would tend to be shortened by the occurrence of reinforcement. Although reinforced presses themselves never constituted a substantial proportion of the total number, one might suppose that such occurrences could differentially reinforce briefer presses. The average reinforced press was probably shorter than the average duration of all presses. Although such an explanation cannot be ruled out entirely, it assumes that the click of the solenoid that presented the reinforcer exerted little or no stimulus control. Since the rats were trained to approach the dipper at the sound of the solenoid, one might suppose

Fig. 5. Frequency distributions of durations of lever presses for the last three days' performance with a VI 80-sec schedule of reinforcement. AVG indicates the total pressing time divided by the total number of presses (*N*). Points representing fewer than 1% of *N* were excluded. The broken lines were fitted by inspection. Note the logarithmic ordinate.

they would hold the lever until the click occurred, rather than letting go prematurely. It is unclear, moreover, how such an explanation would account for the exponential distributions of longer presses in Figure 5.

The third possible explanation would attribute the brevity to tendencies inherent in rats' behavior toward food. When a lever is correlated with food presentation, rats come to gnaw and lick it (Peterson, Ackil, Frommer, and Hearst, 1972). In the present experiment, these activities could be inferred from tooth marks and a sticky accumulation on the lever. The rats of Figure 5 were observed to lick and palpate the lever while holding it. Such actions would tend to jiggle the lever, producing several brief "presses" for a single episode of holding. The frequency distributions of Figure 5 support this reasoning. The distributions of short presses would represent the jiggling; the distributions of long presses would represent holding in which the rats' actions maintained the lever in a depressed position continuously for a while.

This explanation suggests also that pressing should tend to be rhythmical, and that other reinforcers, responses, or species should produce other results. These are problems for further research.

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