

## THE MATCHING LAW IN AND WITHIN GROUPS OF RATS<sup>1</sup>

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In each of the two experiments, a group of five rats lived in a complex maze containing four small single-lever operant chambers. In two of these chambers, food was available on variable-interval schedules of reinforcement. In Experiment I, nine combinations of variable intervals were used, and the aggregate lever-pressing rates (by the five rats together) were studied. The log ratio of the rates in the two chambers was linearly related to the log ratio of the reinforcement rates in them; this is an instance of Herrnstein's matching law, as generalized by Baum. Summing over the two food chambers, food consumption decreased, and response output increased, as the time required to earn each pellet increased. In Experiment II, the behavior of individual rats was observed by time-sampling on selected days, while different variable-interval schedules were arranged in the two chambers where food was available. Individual lever-pressing rates for the rats were obtained, and their median bore the same "matching" relationship to the reinforcement rates as the group aggregate in Experiment I. There were differences between the rats in their distribution of time and responses between the two food chambers; these differences were correlated with differences in the proportions of reinforcements the rats obtained from each chamber.

*Key words:* matching law, group operant, multi-operant, economic behavior, demand curve, shopping centers, variable interval, lever press, rats

In its simplest form, Herrnstein's (1970) matching law states that if two schedules of reinforcement are concurrently available, rates of responding on them are in the same proportion as reinforcement rates. The law summarizes much data on choice, especially choice by pigeons between two concurrently available schedules of reinforcement, each imposing a variable interval between reinforcements (*conc VI VI* schedules). There are exceptions, but they mainly concern choice between schedules of different types (*e.g.*, Nevin, 1971; Trevett, Davison, and Williams, 1972). At least some of the exceptions can be accommodated by a gen-

eralization of the matching law proposed by Baum (1974*b*), according to which

$$\log (R_1/R_2) = a \log (r_1/r_2) + b \quad (1)$$

where  $R_i$  and  $r_i$  are the response and reinforcement rates on the  $i$ th schedule and  $a$  and  $b$  are fitting constants. Lobb and Davison (1975) suggested that  $a$  is usually in the range 0.8 to 1.0; the simple matching law would require it to equal 1.0 always.

We are concerned with the relation between psychological experiments on choice, and the choices made by consumers in the course of their economic behavior. The present paper describes experiments with *conc VI VI* schedules under conditions that we tried to make somewhat like those of the real economy. More than one subject had access to the apparatus at a time, the subjects had to obtain all their food by working on the schedules, and access to the schedules was unrestricted. Our purpose was to see whether the matching law would still be useful in this "real-life" (or nearer-to-real-life) situation.

Should the matching law be expected to hold in these experiments? On the one hand, some schedule effects survive relaxation of standard experimental conditions. Grott and

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Neuringer (1974) showed that a group of rats behaves roughly like a single rat on some standard schedules of reinforcement; Morgan, Fitch, Holman, and Lea (1976) used multiple-interval schedules to teach higher-order concepts to free-living pigeons with unrestricted access to the schedules; and Baum (1972, 1974a) obtained matching from a single pigeon with unrestricted access to *conc VI VI*, and from free-living pigeons with virtually unrestricted access (only one pigeon could occupy the apparatus at a time). On the other hand, if different subjects can command two manipulanda, the situation might approximate a simple, rather than a concurrent schedule: as soon as reinforcement is available on each schedule, it might be taken by the subject commanding the corresponding manipulandum. Under these conditions there would be little reason to expect the interaction between schedules that gives rise to matching.

EXPERIMENT I

In the first experiment, the aggregate behavior of a group of rats was studied under a range of *conc VI VI* schedules.

METHOD

Subjects

Five female hooded rats were randomly selected from a group of 10 obtained from Animal Suppliers Ltd, London, aged three months. The remainder were kept as reserves.

Apparatus

Figure 1 shows a scale drawing of a vertical cross-section through the apparatus, and defines the names used for its parts. The staircase and chambers were made of sheet aluminum, the floors were of 1.3-cm galvanized mesh, and the tubes were cylinders of clear plastic. The floors and tubes could be lifted out for washing; when this was done, spares were substituted. The staircase was lit by 0.6-W bulbs in flush mountings fixed to the rear wall at the heights indicated. The front of the staircase was formed of a neutral density plastic door, divided horizontally at the level of stair 4, and hinged at the left. The front of each chamber was a neutral density plastic door, hinged at the right. Sheet aluminum panels could be inserted cut off the tubes from the staircase or the chambers. The

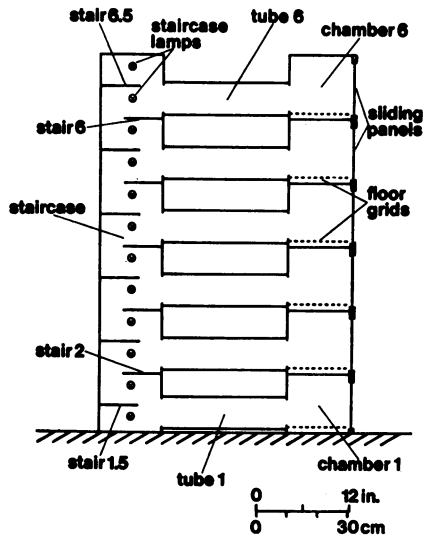


Fig. 1. Vertical cross-section through the apparatus, drawn to scale except for the thicknesses of walls. Note that the tubes were cylindrical, and that the depth of the staircase and chambers was 15 cm. The staircase lamps were mounted on the rear wall.

sliding panels that formed the right-hand walls of the chambers were either blank sheets of aluminum, or operant test units of the design illustrated in Figure 2. The 3-W lamp above the lever (barlight) was mounted flush. The foodtray was recessed, could be lit from behind and above by a 3-W traylight, and was closed by a translucent flap (panel) that operated a microswitch. The retractable lever operated a sealed-reed switch when depressed

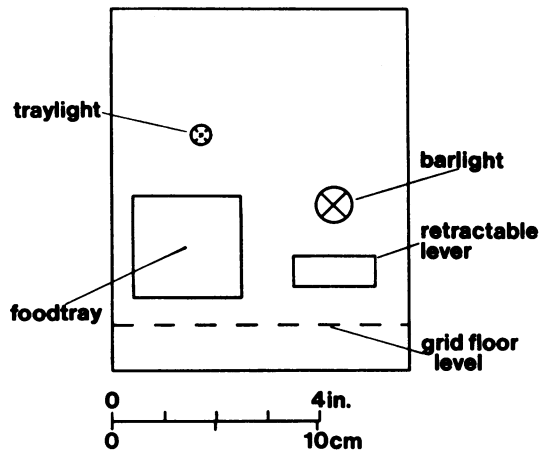


Fig. 2. Elevation of the operant panels used in some chambers, drawn to scale.

with a force adjustable between 0.05 and 0.09 N. The foodtray could be supplied either with liquid from a 0.05-ml dipper or with 45-mg pellets. The levers, foodtrays, dippers, and pellet feeders were obtained commercially (Campden Instruments Ltd, London), but the pellet feeders were modified to take several thousand pellets, and hydrostatic systems were used to keep the dipper reservoirs topped up from 500-ml flasks.

The apparatus was housed in an air-conditioned room, which was lit by fluorescent tubes from 2000 to 0800 hr, and by dim red light at other times. Ambient temperature was maintained at 21°C. Masking noise was not used. Conventional electromechanical programming apparatus was in the same room, but out of sight from the chambers. It included filmstrip timers to control the variable intervals; the rats were watched periodically for signs that they were detecting the clicks from these timers, but no evidence was found that they could discriminate significant noises among the general electromechanical clatter.

#### Pretraining

The rats were not deprived of food or water before they were first put into the apparatus. On the first day, 10 g of standard laboratory diet was put in each chamber, and a water bottle was fixed in Chamber 1; all chambers had blank panels at their right ends. During the next 20 days, feeder panels were installed in Chambers 2 and 5 and dipper panels in Chambers 3 and 4, and the rats were trained to obtain all their food and water by pressing the levers in those chambers on a continuous reinforcement schedule: a single lever press operated the feeder, turned the traylight on and the barlight off; the lights changed back again when the tray flap next closed, that is, when a rat next withdrew its head from the foodtray. No "shaping" was done, but the contingencies were introduced gradually: the operant panels were installed one at a time, lever training was preceded by magazine training (in which the feeders were operated at regular intervals, or whenever the foodtray panel closed), and the lever force requirements were initially set to a minimum. The interchange of signal lights at pellet or water delivery was used throughout the experiment. At the end of pretraining, all lever force requirements were set to the maximum.

Table 1

Experiment I. Sequence of experimental conditions, and absolute aggregate response and reinforcement rates observed under each. Data are medians of five daily aggregates; note that response and reinforcement rates are multiplied by 100.

Chamber: Condition	Variable Interval (sec)		Dura- tion (days)	Responses/ Sec <sup>a</sup> (× 100)		Reinforce- ments/ Sec <sup>a</sup> (× 100)	
	2	5		2	5	2	5
1	45	15	20	1.69	4.20	0.45	1.17
2	15	45	12	4.44	1.00	1.46	0.20
3	30	30	16	3.59	2.41	0.81	0.65
4	45	30	12	2.94	3.26	0.62	0.92
5	30	45	10	3.62	2.59	0.84	0.64
6	15	15	7	2.76	2.13	0.78	0.77
7	30	15	29	2.29	4.80	0.59	1.33
8	15	30	47	3.60	1.40	1.06	0.34
9	45	45	36	2.45	3.50	0.74	1.00

<sup>a</sup>To convert the figures in these columns to responses or reinforcements per day, multiply by 864.

#### Procedure

The schedules of food reinforcement in Chambers 2 and 5 were then taken through the values given in Table 1. The variable-interval timers ran continuously, but reinforcements were lost if they became due in a chamber while its traylight was on. The schedules were changed when at least five days had been completed without known apparatus failure or procedural error. These five days were required to be consecutive except for at most one day's interruption. The schedules were not changed if either the response rates in the chambers, or their ratio, showed any obvious trend over the five-day period. Total lever responses in all chambers, and total reinforcements in Chambers 2 and 5, were recorded daily, as nearly as possible at 1200.

#### RESULTS

The rats moved freely through the apparatus at all stages of the experiment. They were more active in the dark (daytime) period than in the light. They slept polyphasically, usually in one or two huddles, in any of the chambers or on stairs 1 or 6.5. After a few weeks, they showed little reaction to the experimenters' entering the room, or even blocking off parts of the apparatus for maintenance.

Figure 3 shows the relative response rate in Chamber 2 (Chamber 2 responses/Chamber

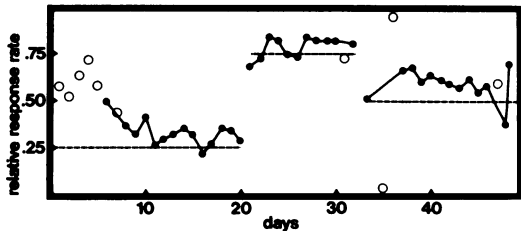


Fig. 3. Experiment I. Proportion of all lever presses made in food chambers that were made in Chamber 2, for the first three schedule conditions. Each point shows data from one day: open circles are used for days where there was a known apparatus failure or procedural error. The broken horizontal lines show the programmed relative reinforcement rates in Chamber 2; in order, the schedules in Chamber 2 in the three conditions were VI 45-, 15-, and 30-sec.

2 + Chamber 5 responses) over the first three *conc* VI-VI conditions, illustrating the course of adaptation to new schedules and the variability of relative response rate within conditions.

Data are presented below as medians over the last five errorless days in each condition. Figure 4 shows the ratio of the response rates in Chambers 2 and 5, as a function of the ratio of reinforcement rates. The data are plotted on logarithmic scales as recommended by Baum (1974b); the figure includes the linear regression of  $Y$  on  $X$ , and the line predicted by the simplest version of the matching law. Ratios of reinforcement rates can be derived in two ways, and results are shown in terms of both the programmed ratio, derived from the variable-interval schedules used, and the observed ratio, derived from the number of reinforcements actually delivered in the two chambers. The regression lines were obtained by standard techniques; it could be argued that these are not strictly appropriate for the observed reinforcement ratios, which are subject to errors of observation. A method appropriate in this case is given by Kendall and Stuart (1967, paragraph 29.20), but even under the worst-case assumption that the reinforcement ratio suffers from as much error as the response ratio, very much the same result is obtained as by the simple method used here. Both by standard or by more sophisticated methods, the regression line for the obtained reinforcement ratios has a slope significantly less than 1.0 ( $p < 0.05$ ).

Figure 5 shows three functions relevant to the attempt to analyze the situation as a model

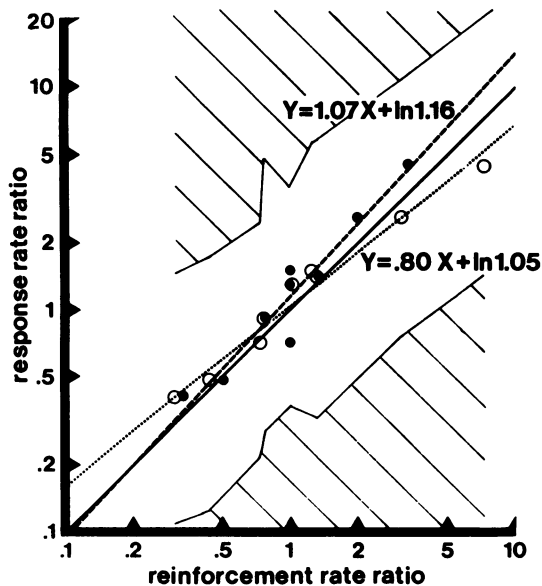


Fig. 4. Experiment I. Ratio of lever-press rate in Chamber 2 to that in Chamber 5, as a function of the ratio of reinforcement rates, on logarithmic coordinates. Data are medians of five daily aggregates. Filled circles and the broken regression line are for data plotted against ratios of programmed reinforcement rates, open circles and the dotted regression line are for data plotted against ratios of obtained reinforcement rates. The solid diagonal line gives the prediction from the simple matching law.

economy. The abscissa is the mean time that had to elapse, according to the schedules, between successive pellet deliveries anywhere in the apparatus; it may be thought of as the average "price" of a food pellet in time units. Data for continuous reinforcement are plotted

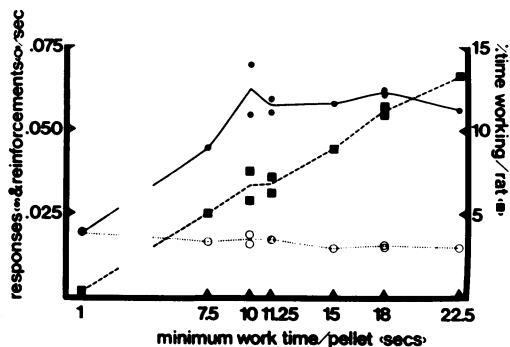


Fig. 5. Experiment I. Response rates, reinforcement rate, and estimated time committed to working for food, as a function of the programmed minimum time between pellet deliveries. Data are medians of five daily aggregates; the left-most points are disconnected because the abscissa value is a rough estimate.

against a "price" of 1 sec, though this is obviously an idealization. The ordinate shows the aggregate rate of earning pellets, the aggregate rate of leverpressing, and an estimate of the proportion of the day committed to earning food per rat. The first two of these were totalled across Chambers 2 and 5; corresponding data for the individual chambers are reported in Table 1. The time committed was estimated by multiplying the number of pellets earned in each chamber by the variable interval in force there, adding the results for the two chambers together, and dividing by the number of rats and the length of the day.

#### DISCUSSION

The log ratio of response rates was approximately equal to the log ratio of programmed reinforcement rates (Figure 4), despite considerable day-to-day variation in relative response rates, and not infrequent apparatus trouble (Figure 3). When obtained reinforcement-rate ratios were used, response-rate ratios did not match them exactly; the slope of the regression line was less than one, a condition that Baum (1974b) called "undermatching". Lobb and Davison (1975) found a similar degree of undermatching in experiments on pigeons with *conc VI VI* schedules, and they argued that undermatching of response ratios to obtained reinforcement ratios is typical. Whether programmed or obtained reinforcement ratios were used, the coefficients of linear correlation in the present experiment were high (0.95 and 0.98 respectively). Baum's (1974b) generalization of the matching law therefore accounted for almost all the variance in the data, and the results were quantitatively and qualitatively consistent with those from more conventional apparatus and more conventional subjects (investigations of matching with rats are rare; for an example, see Mazur, 1975).

There are two reasons for caution about the results. First, Herrnstein (1970) pointed out that when response and reinforcement rates are similar, matching to obtained reinforcement rates may be produced artifactually, since for a reinforcement to be obtained a response must occur. Herrnstein investigated the limits that this constraint imposes on relative response rate; his formulae can be adapted for log response ratios, and the areas where the log response ratios could not lie have been shaded in Figure 4. It is clear from the figure

that this artifact was not responsible for the good fit of the generalized matching law.

A more serious problem is that the obtained reinforcement rates were an order of magnitude less than the programmed rates. The possibility therefore exists that the obtained reinforcement ratios did not cause, but were caused by, the rats' allocation of time and responding to the two chambers. For this reason, we lay more stress on the match of response-rate ratio to programmed reinforcement ratio (which is directly manipulable), than on the very nearly linear relationship of log response ratio to log obtained reinforcement ratio. The coincidence between the latter relation and that observed by Lobb and Davison (1975) is undoubtedly striking; but under plausible assumptions, it can be shown that exact matching of response ratio to programmed reinforcement ratio, and a low rate of switching between chambers, imply a linear relationship between log response ratio and log obtained reinforcement ratio, with a slope between 0.5 and 1.0. The observed value (0.80) is in the middle of this range. Even if the origin of the relationship to observed reinforcement ratios is uncertain, however, the near match between response ratios and programmed reinforcement ratios is sufficient to establish that the present results are consistent with the published literature on *conc VI VI*.

One reason why the obtained reinforcement ratio is normally used is that it is the variable most likely to be controlling behavior; the subject cannot know the schedules except by the reinforcements they yield. In the present situation, the variable controlling behavior could well have been the reinforcement rates experienced during long, uninterrupted periods of working in single chambers; since such periods would not have been of any standard length, it is plausible that the rats should have learned about the programmed reinforcement rates independently.

It remains to show that the experimental situation did function in some respects as a model economy. Figure 5 shows that, as the average cost of a pellet increased, the rats decreased their total intake of food. The time required to earn what food they took increased, and so did the number of responses made. The first two of these trends were significant (Kendall's tau values of  $-0.49$  and  $0.71$ ,  $p < 0.05$ ), but the striking aspect of the

data is that there was very little difference in food intake between the *conc VI VI* conditions. The only substantial drop in intake occurred on going from continuous reinforcement to *conc VI VI*.

Time required to earn a pellet is chosen as the analog of price in this situation because, like money, time spent on working for one commodity cannot be spent on working for another (*cf.* Becker, 1965). If the analogy is accepted, the open circles of Figure 5 represent the economist's demand curve, the function that relates the quantity of a good consumed to its price (*cf.* Lancaster, 1969, p. 13). The fact that the filled squares form an increasing function means that demand for food was "inelastic" (strictly, had elasticity less than one); that is, a given percentage price increase caused a smaller percentage decrease in quantity consumed, and hence as price increased so did the expenditure of time on food. Inelastic demand for food has been found in a number of studies in which isolated animals lived in operant apparatus and obtained all their food on fixed-ratio schedules (Collier, Hirsch, and Hamlin, 1972; Hirsch and Collier, 1974; Hogan, Kleist, and Hutchings, 1970, Experiment 1b; Logan, 1964). It is also found in the real economy: if all food is considered together, demand for it is inelastic, and so is demand for the majority of individual foodstuffs (Stone, 1954, Chapter 20).

Herrnstein (1970) derived matching from the following equation for the dependence of  $R_i$ , the response rate on the  $i$ th schedule, on  $r_i$ , the corresponding observed reinforcement rate:

$$R_i = \frac{kr_i}{r_o + \sum_1 r_i} \quad (2)$$

where  $r_o$  and  $k$  are constants. At first sight, (2) is inconsistent with inelastic demand, for the equation implies that other things equal the response rate will be an increasing function of reinforcement rate, and inelastic demand implies the opposite. However, it is apparent from Figure 5 that at least within the *conc VI VI* conditions, both overall response rate and overall observed reinforcement rate were roughly constant, and (2) was therefore satisfied. It fails if the continuous reinforcement data are taken into account, and it would fail with the fixed-ratio data cited above; but that

is part of a wider problem, for the difficulties in applying matching principles to ratio schedules are well known (*e.g.*, Herrnstein and Loveland, 1975).

## EXPERIMENT II

Experiment I showed that matching, at least in the generalized form of Baum (1974b), held for the aggregate behavior of a group of rats. But nothing was shown about the behavior of individuals. Aggregate matching might result from similar behavior by all members of the group. On the other hand, there might be consistent differences between individuals in undermatching or bias, the constants  $a$  and  $b$  of Equation 1. These could be associated with a more general dominance or territoriality respectively: a dominant rat might be expected to overmatch, that is to monopolize the better schedule in a situation where the group as a whole matched or undermatched (on the other hand, access to a limited resource is not a good measure of dominance in rats, according to Syme, Pollard, Syme, and Reid, 1974). Or it might be that individuals matched to their personal ratios of reinforcement rates, which might not be the same as either the programmed ratios or the ratio obtained by the group as a whole.

To investigate these possibilities, a similar group of rats was used in the same apparatus, with two of the concurrent schedule conditions from Experiment I. The rats were observed by time-sampling for 90-min periods on selected days to see whether the aggregate results of Experiment I were true of individuals. The rats were mildly deprived of food so as to concentrate activity into the chosen observation periods.

## METHOD

### Subjects

Five female hooded rats were selected at random from a new batch of ten, obtained as before.

### Apparatus

The apparatus was the same as in Experiment I, except that the floors of the chambers were lined with paper towels and sawdust beneath the grids. The towels, grids, and tubes were changed, and the doors were washed about every eight days (one level of the appa-

ratus was cleaned on each day, except that on the seventh day the staircase was cleaned, and no cleaning was done on Sundays). A keyboard and indicator panel was used during observation periods. It was connected to a digital computer and controlled by a general experimental control system, ONLI,<sup>2</sup> which also collected data.

### *Pretraining*

Pretraining was carried out as in Experiment I, but more quickly and systematically. Two food panels and two water panels were introduced at once, but at first, water bottles were fixed so that their spouts poked through the foodtrays of the dipper chambers (numbers 3 and 5), with the foodtray flaps removed. Magazine and lever training for food reinforcement were then carried out in the two food chambers (numbers 2 and 6), making all changes in contingencies simultaneously in the two chambers. The water bottles were then removed from Chambers 3 and 5, and dipper and lever training for water reinforcement completed, again making changes simultaneously in the two chambers. In pretraining and throughout the experiment, the presence of a reinforcer in a foodtray was indicated by the interchange of tray- and barlights, as in Experiment I.

### *Procedure*

Four days after lever pressing had been established in all four chambers, variable-interval (VI) 15-sec schedules were introduced in the food chambers. These schedules were in force for 23 days, and were followed by seven days with VI 45-sec in Chamber 6 and VI 15-sec in Chamber 2; 46 days with the reverse; and 29 days following a second reversal. The last three conditions were those of the experiment proper. The decision to change conditions was based on the observer's impression that group interaction had stabilized.

Except for the first five days with VI 15-sec in both food compartments, the two food chambers were darkened, their levers retracted and their schedules made inoperative, at 1000 hr each day. The chambers returned to normal at some time between 1600 and 1715, and on some days a 90-min observation then began. An hour before each observation session, the

rats were marked with distinct symbols on both flanks. Observations were made by time and activity sampling. A light flashed on the observer's keyboard to indicate which of five chambers (numbers 6 to 2 in that order) and which of three activities (present in chamber, contacting lever, eating/drinking) should be observed. The observer responded by pressing a button for each rat that was engaged in the specified activity in the specified chamber. Errors could be corrected until a "data complete" button was pressed, after which the next activity or chamber was selected after a half-second pause. The whole cycle was repeated every 30 sec; if a cycle took longer than 30 sec to complete, the next one started as soon as the extended one finished, and the sequence was brought back into phase as soon as possible. Note that the "contacting lever" observation was made visually; no attempt was made to gate it with the switch operated by the lever.

There were 5, 12, and 11 observation periods in the three conditions with unequal VI schedules. Some observation periods were also undertaken while the VI-15 sec schedules were in force in both chambers, but these were exploratory: the conditions of observation were varied to find the most suitable procedure. Data from these conditions are not reported. Their major result was that 90 min was a long enough session to observe each rat have a substantial "meal" and then go to sleep.

In some observation sessions, a closed-circuit television camera, adapted for low illuminations, was used to assist the observer. The camera could be swung to as to show any chamber on a monitor placed where the observer could watch it and the apparatus together.

### RESULTS

Table 2 gives the aggregate response and reinforcement rates, both absolute and relative, observed during the observation sessions and during the periods that began with observations sessions and ended with the withdrawal of the levers in the food chambers at 1000 next day. Table 3 gives, for each rat, the number of occasions on which each type of behavior monitored (present in chamber, lever pressing, eating) was observed in Chambers 2 and 6. All these data are reported as medians over all the observation sessions in each schedule condition.

<sup>2</sup>See Footnote 1.

Table 2

Experiment II. Aggregate data from the observation sessions and the days that started with them; all data are medians across all observation sessions in a schedule condition.

	Schedule Condition					
	1		2		3	
	2	6	2	6	2	6
Chamber:						
VI (sec):	15	45	45	15	15	45
Observation sessions						
Lever-press rate (/sec)	0.129	0.074	0.089	0.239	0.226	0.122
Reinforcement rate (/sec)	0.0298	0.0065	0.0111	0.0515	0.0443	0.0124
Relative lever-press rate*	0.70		0.28		0.66	
Relative reinforcement rate*	0.82		0.19		0.78	
Periods from the start of an observation session until 1000 next day						
Lever-press rate (/sec)	0.076	0.034	0.025	0.084	0.082	0.021
Reinforcement rate (/sec)	0.0155	0.0030	0.0044	0.0200	0.0182	0.0035
Relative lever-press rate*	0.68		0.25		0.77	
Relative reinforcement rate*	0.82		0.18		0.85	

\*Chamber 2 rate/(Chamber 2 rate + Chamber 6 rate).

Figure 6 shows the relative lever contact score in Chamber 2 for each rat (number of times the rat was observed in contact with the lever in Chamber 2/number of times it was observed in contact with the lever in Chamber 2 or 6). Data are shown for all observation sessions with unequal VI schedules. The concordance between sessions in ordering the rats by relative lever-contact score was significant

Table 3

Experiment II. Median number of each type of observation made of each rat in each schedule condition, out of a maximum of 180.

Rat	Activity	Schedule Condition					
		1		2		3	
		2	6	2	6	2	6
	Chamber:						
	VI (sec):	15	45	45	15	15	45
1	Present	15	15	19	51	36	29
	Eating	13	15	3	12	11	3
	Lever-contact	13	15	4	12	12	11
2	Present	14	10	10	84	65	33
	Eating	15	10	1	24	17	3
	Lever-contact	15	10	2	29	21	5
3	Present	22	6	21	57	44	11
	Eating	21	5	2	16	10	1
	Lever-contact	15	5	6	14	14	2
4	Present	25	1	32	45	28	40
	Eating	21	1	4	12	7	4
	Lever-contact	22	1	13	21	17	14
5	Present	21	7	20	50	48	9
	Eating	22	3	4	16	13	1
	Lever-contact	22	3	4	20	16	4

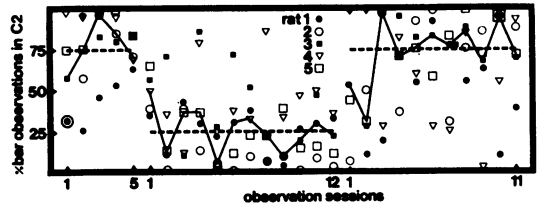


Fig. 6. Experiment II. Proportion of all observations of lever contact by each rat that were made in Chamber 2. Data are shown for each observation session in the second and third schedule conditions of the experiment. Solid lines connect the medians for each session; the broken horizontal lines show relative programmed reinforcement rates in Chamber 2.

in the first two conditions but not the third (Kendall  $W = 0.52$ ,  $p < 0.05$ ;  $W = 0.28$ ,  $p < 0.01$ ;  $W = 0.13$ ,  $p > 0.05$ ). Averaging over days by summing ranks, the order of the rats by relative lever-contact score in Chamber 2 was, from lowest to highest: Rat 1, 2, 3, 4, 5 in Condition 1; Rat 2, 5, 1, 3, 4 in Condition 2; Rat 1, 4, 5, 2, 3, in Condition 3. The concordance between these three orders is not significant, whether the second order is used directly (so as to test for consistent differences in relative response rate in Chamber 2:  $W = 0.38$ ,  $p = 0.41$ ) or in reverse (so as to test for consistent differences in relative response rate in the preferable chamber:  $W = 0.38$ ,  $p = 0.41$ , identity coincidental). Very similar results, but with slightly more day-to-day variation, were obtained for the present-in-chamber observations.



## DISCUSSION

The median relative lever-contact scores for Chamber 2 are connected in Figure 6. They did not differ significantly from the programmed relative reinforcement rates (also shown in the figure) in any condition (two-tailed signs tests over sessions,  $p = 1.0$  in each condition). Thus, the matching law held between visual observations of lever-pressing and programmed reinforcement rates; this result agrees with that of Experiment I, and suggests that the observations of lever pressing were reasonably accurate. The aggregate relative response and reinforcement rates (Table 2) are also consistent with Experiment I, and again suggest matching to programmed relative reinforcement rates, but undermatching to observed relative reinforcement rates.

Despite some significant differences between the rats in relative lever-contact score, the concordance among the three sets of conditions gave no indication that individuals differed in dominance or had consistent chamber biases. Some rats at some times were seen to defend a chamber, or a lever, but there was nothing in the observations or the quantitative data to suggest that this was territorial defense; at some time or other, every rat was seen to displace every other from both chambers. The only obvious consistency in individual behavior concerned Rat 1. It undermatched consistently, and was also the smallest and lightest rat; it may have been displaced from the more favorable chamber unusually often, or may have obtained an unusually low percentage of the reinforcements delivered when it was there. But even Rat 1 was often seen to displace other rats.

The differences between rats within conditions were therefore not attributable to anything that could be traced from condition to condition. Might they have been caused by differences in the ratio of reinforcement rates obtained by the rats under each condition? Because of competition, a single rat would not necessarily obtain the reinforcement rate programmed for a chamber even if it were continuously present there. The "eating" observation scores were used to estimate each rat's obtained ratio of reinforcement rates in the two chambers. The lever-contact scores were numerically so close to the eating scores that an artifactual match was inevitable (see Ta-

ble 3); but the present-in-chamber scores were an order of magnitude larger, so they could sensibly be plotted against the eating scores. Figure 7 shows, on log scales, the ratio of present-in-chamber scores as a function of the ratio of eating scores in the two food chambers. Each data point gives median data from one rat in one schedule condition; no data from the first schedule condition are shown, because the criteria used for eating and lever contact were too liberal in that condition, so that all three scores were virtually identical. Regression lines and correlation coefficients were obtained for the other two schedule conditions separately. The correlation between log present-in-chamber ratio and log eating ratio was significant in schedule Condition 2, but not in schedule Condition 3 ( $r = 0.89$ ,  $p = 0.045$ , and  $r = 0.47$ ,  $p = 0.47$ , respectively).

Thus, at least in schedule Condition 2, the likelihood that a rat would be seen in one chamber rather than the other was significantly correlated with the likelihood that it would be seen to eat in that chamber, taking the correlation across the group of rats, all of whom were working at a constant programmed ratio of reinforcement rates. But, as in Experi-

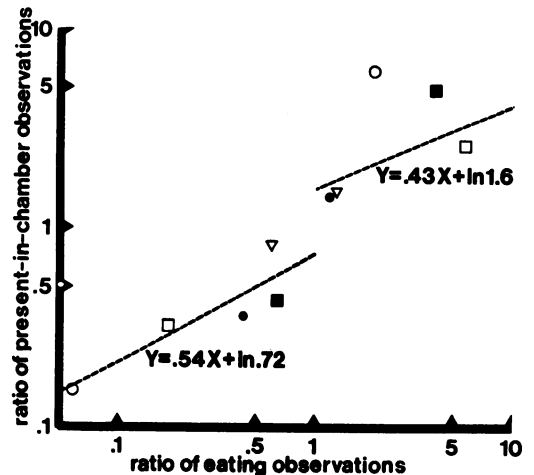


Fig. 7. Ratio of present-in-chamber observations of each rat (number of observations in Chamber 2/number in Chamber 6) as a function of the corresponding ratio of observations of eating, on logarithmic scales. Each data point gives the median for one rat over all the observation sessions in one schedule condition; the points and the regression line in the lower-left quadrant are from schedule Condition 3. The different symbols indicate different rats, using the same code as in Figure 6.

ment I, it is unclear which is the independent variable here. To be sure that the rats were reacting to differences in the contingencies they experienced, we need a measure that could not be determined by time allocation, and yet reflects the different rats' success in obtaining pellets from each chamber, given the competitive situation. The following measure was devised. Each observation session was divided into 5-min blocks. Within each of these, each rat's competitive success in each chamber was assessed as the proportion of observations of eating in that chamber that were attributed to that rat. This success proportion was then averaged over all the 5-min blocks in the session, excluding blocks where the rat was never observed in the chamber (the exclusion is important; without it, a relative competitive success score would reduce to a simple transform of the relative eating score used above). An adjusted reinforcement rate for each rat in each chamber was then obtained by multiplying the programmed reinforcement rate in the chamber by the rat's mean competitive success there. Figure 8 shows the ratio of present-in-chamber scores as a function of the ratio of programmed reinforcement rates thus adjusted; we call the latter "socially programmed" reinforcement rates, because they are derived from the schedule arranged by the experimenter together with the rats' social interactions. The details of Figure 8 are the same as for Figure 7. The correlation between log ratio of present-in-chamber scores and log ratio of socially programmed reinforcement rates was not significant for either schedule condition ( $r = 0.65$ ,  $p = 0.24$  for schedule Condition 2;  $r = 0.62$ ,  $p = 0.27$  for schedule Condition 3). However, the regression lines (shown in Figure 8) were quite close to matching, and noticeably closer than those shown in Figure 7. This difference is consistent with the better match to programmed than to observed reinforcement ratios observed for aggregate data in both Experiments I and II. The implication is that the same processes operated between rats within a condition as operated for the aggregate between conditions; but the conclusion from this analysis must be that there is no firm evidence that the rats' individual experiences of the two chambers affected their tendencies to visit them under constant programmed schedules. The converse process may have occurred.

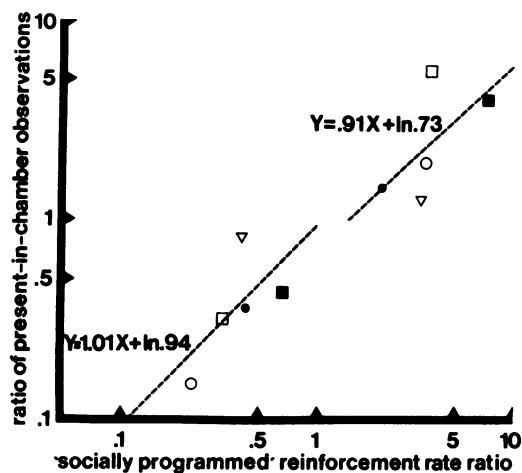


Fig. 8. Ratio of present-in-chamber observations of each rat (number of observations in Chamber 2/number in Chamber 6) as a function of the corresponding ratio of "socially programmed" reinforcement rates. The socially programmed reinforcement rates were derived from the programmed reinforcement rates by discounting for each rat's competitive success in each chamber. The details of the figure are as for Figure 7.

In summary, then, there is no conclusive evidence for individual differences due to territoriality or dominance between conditions, or due to differences in competitive success within conditions. In fact, if the lever-contact scores from Table 3 are regarded as response rates corresponding to relative programmed reinforcement rates of 0.25 (Condition 2) and 0.75 (Condition 3), the individual deviations from matching are only twice as great as those observed in straightforward *conc VI VI* experiments with pigeons by Catania (1963, Figure 3, left column), using the same relative reinforcement rates.

#### GENERAL DISCUSSION

The matching law, as generalized by Baum (1974b), provided a useful summary of the behavior of rats choosing between alternative sources of food reinforcement on variable-interval schedules. This was true both of the aggregate behavior of the group, and of the behavior of individuals within the group. Behavior differed only slightly (though significantly) from that predicted by the simple matching law of Herrnstein (1961, 1970).

These results extend the generality of the matching law, but they also have implications for the origins of matching. Shimp (1966, 1969)

argued that matching occurs because animals make whatever response is instantaneously most likely to lead to reinforcement; Mackintosh (1974) appealed to Shimp's argument, and asserted that matching is an instance of a general principle of reinforcement maximization akin to the principle of consumer rationality used in the microeconomic theory of demand (e.g., Lancaster, 1969). But it is not at all clear that matching could result from instantaneous maximizing in the present experiments. If a rat left one chamber to obtain a pellet that had been set up in the other chamber, it took a considerable risk of failing to get that pellet (because another rat was concurrently occupying the other chamber) and losing the next one in its original chamber (because another rat had come and taken it). It is more plausible to explain matching in terms of the different response rates supported by the different schedules used; in terms, that is, of the psychology of learning and habit, rather than the psychology of rational decision.

In one respect, the rats did behave like consumers in the economy: they showed inelastic demand for food, an essential commodity. Such behavior is conventionally deduced from consumer rationality, but it would be wrong to conclude that the rats were, therefore, partly rational. Real consumers, as distinct from the ideal consumers of economic theory, are at best approximately rational (Reynaud, 1954, p. 118 ff.); in many respects, their behavior is a matter of habit (Katona, 1953).

Since matching was found in a situation that was constructed to be a little like a real economy, and since real economic behavior was successfully mimicked in at least one respect, it seems worth asking whether any phenomenon like matching can be found in the economy. A possible analog is in Equation 3, which gives a law formulated by Huff (1962) to predict consumers' probabilities of visiting different shopping centers:

$$R_j / \sum_j R_j = \frac{S_j / (T_j^\lambda)}{\sum_j (S_j / (T_j^\lambda))} \quad (3)$$

In (3),  $R_j$  is the number of visits to the  $j$ th shopping center,  $S_j$  is its size, and  $T_j$  is the travel time to it. For two shopping centers of the same size, we have

$$R_1 / R_2 = \left[ \frac{1/T_1}{1/T_2} \right]^\lambda \quad (4)$$

If we look on  $1/T_j$  as a reinforcement rate, (4) is a form of Equation 1, Baum's (1974b) generalization of the matching law; and of the matching law itself if  $\lambda$  (a fitting constant) equals one. Huff found values of 2.6 to 3.7 for  $\lambda$  when the commodity in question was clothing, and 2.1 to 3.3 when it was furniture.

For two shopping centers of different size, we have

$$R_1 / R_2 = \frac{S_1 / (T_1^\lambda)}{S_2 / (T_2^\lambda)} \quad (5)$$

The size of a shopping center might be proportional to the quantity of goods sought there, and thus analogous to amount of reward. Equation 5 would then not be consistent with Baum's proposals for choice between schedules offering different amounts of reward, for according to Baum the entire quotient ( $S_j / T_j$ ) should be raised to the power  $\lambda$  (or  $a$  in Baum's terminology). However, Todorov (1973) found that when the rate and the amount of reinforcement were both varied in *conc VI VI* schedules, pigeons' choices were less affected by the relative amount than by the relative rate of reinforcement. This result is consistent with the amount being raised to a lower power than the rate in an extension of Equation 1, and it thus has something at least in common with Huff's formula.

The empirical base of Huff's law is much less secure than that of the matching law (for some criticisms of it, and of related models, see Mason and Moore, 1970). The point of introducing it here, and the point of the combined matching and "economic" analysis of the results of Experiment I, is to suggest that consumer behavior, and economic behavior in general, is a proper field for the application of operant psychology. Skinner (1953, p. 100 ff.) compared different manners of paying wages with different schedules of reinforcement, but there has been little serious attempt to make an experimental analysis of economic phenomena. The most important development has been the use of token economies (e.g., Ayllon and Azrin, 1968), sometimes explicitly linked to an economic analysis (Winkler, 1971), and of multi-operant environments (e.g., Findley, 1966). But much more could be done, along the lines of applying economic concepts

to standard operant paradigms (as in Green and Rachlin, 1975, or Kagel, Battalio, Rachlin, Green, Basmann, and Klemm, 1975), or showing that phenomena known in individuals also apply to groups (as in Grott and Neuringer, 1974). The present experiments have shown that both these last strategies can be pursued simultaneously.

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