PREFERENCE FOR QUALITATIVELY DIFFERENT REINFORCERS¹

VALERIE HOLLARD AND M. C. DAVISON

UNIVERSITY OF AUCKLAND, NEW ZEALAND

Three pigeons were studied under two-key concurrent variable-interval schedules with food as the reinforcer on one key and ectostriatal brain stimulation as the reinforcer on the other. Brain-stimulation parameters were kept constant while the rate of food reinforcement availability was varied. The results showed that qualitatively different reinforcers could be handled in the same theoretical framework that applies when choice is between different rates, immediacies, and amounts of a single reinforcer.

In the study of reinforcement it is now possible to state quantitative laws about the reinforcing properties of different rates (Herrnstein, 1961; 1970), delays (Chung, 1965; Chung and Herrnstein, 1967), and magnitudes (Catania, 1963; Brownstein 1971) of a single type of reinforcer. Using concurrent variable-interval (VI) schedules, these workers have documented the following relations: if P_1 and P_2 are the numbers of responses per session to the keys associated with two schedules, and responses to the two keys are reinforced at different rates of reinforcement (r_1 and r_2), or with two different immediacies of reinforcement (reciprocal of delay, i_1 and i_2), or with two different amounts of reinforcement (a_1 and a_2), then:

$$\frac{P_1}{P_2} = \frac{r_1}{r_2} \quad \dots (1)$$

$$\frac{P_1}{P_2} = \frac{i_1}{i_2}$$

$$\frac{P_1}{P_2} = \frac{a_1}{a_2}$$

These relations apply when only one of these variables is manipulated in isolation. The manner in which these variables combine when more than one is varied has been dis-

cussed by Baum and Rachlin (1969). They suggest:

$$\frac{P_1}{P_2} = \frac{r_1 i_1 a_1}{r_2 i_2 a_2} \quad \dots (2)$$

Since time allocation matches response allocation in concurrent VI schedules (Catania, 1966; Stubbs and Pliskoff, 1969), the above relation will also apply to the ratio of the time spent responding to the schedules, T_1/T_2 .

The present experiment investigated the values of two qualitatively differing reinforcers, food and brain stimulation, in this theoretical context. It is assumed that qualitatively different reinforcers are subject to the same basic laws of choice as single reinforcers differing in magnitude, rate, or immediacy (Equation 1). Thus, if q_1 and q_2 are measures of the values of two different reinforcers, then:

$$\frac{P_1}{P_2} = \frac{q_1}{q_2} \quad \dots (3)$$

It is not, however, possible to vary the qualities of different reinforcers in the same way as it is possible to vary, for example, the rates of a reinforcer. The relative values of qualitatively differing reinforcers should remain constant when the quantitative parameters of those reinforcers (Equation 2) are varied. Hence, for two different reinforcers, the rate, duration, or immediacy of reinforcement, either singly or in combination, could be varied without affecting the constant contribution of the type of reinforcer to reinforcement value. Thus, for varied rates of two different reinforcers:

$$\frac{P_1}{P_2} = \frac{r_1 q_1}{r_2 q_2} \quad \dots (4)$$

¹This experiment is to be submitted as a partial requirement for the degree of Doctor of Philosophy by the first author. Reprints may be obtained from either author, Department of Psychology, University of Auckland, Private Bag, Auckland, New Zealand. Supported in part by grant AG 140 PSY 14 from the University Grants Committee to the second author.

If the choice between different rates of reinforcing brain stimulation and food corresponds to equation (4), then the validity of equation (3) will have been demonstrated, allowing qualitative differences between reinforcers to be handled in terms of value (Baum and Rachlin, 1969) in precisely the same way as quantitative differences in reinforcement.

METHOD

Subjects

Three homing pigeons with previous experience under similar experimental conditions were maintained at $80\% \pm 10$ g of their free-feeding body weights. They were numbered 93, 95, and 119. Stainless steel monopolar electrodes insulated with acrylic enamel except at the tip were implanted bilaterally (Webster and Beale, 1970). The electrodes were aimed at the ectostriatum following the stereotaxic procedure of Karten and Hodos (1967). A wire loop on the surface of the skull acted as an indifferent electrode, and stimulation was between the indifferent and one side.

Histological analysis of electrode placements is not yet available for these birds as they are now taking part in further experiments. These data will be published when they are available.

Apparatus

The sound-attenuated experimental chamber contained two response keys 0.75 in. (2 cm) in diameter, 6 in. (15.5 cm) apart and 8 in. (20.5 cm) from the grid floor. An exhaust fan helped mask external noise. The grain magazine was situated 2.5 in. (6.5 cm) from the floor midway between the two keys. After each session the birds were given supplementary feeding to maintain body weights.

Relay equipment controlled all experimental events and all data were recorded on impulse counters.

Procedure

Since the subjects had previously worked under concurrent schedules of food and brain stimulation reinforcement, no explicit key-peck or schedule training was required. The animals were placed directly under the first experimental condition.

In the experimental chamber, the left key was always red. The right key was green except during food or brain stimulation reinforcement,

when it was darkened and inoperative. No further illumination was provided in the chamber. Feedback in the form of a 35-msec burst of white noise followed all pecks to both lighted keys exceeding approximately 0.196 N.

Food reinforcement was 3-sec access to a hopper containing wheat. Brain stimulation reinforcement was a 15-sec interval in which each key peck produced 0.5-sec of 50-Hz sine wave of adjustable current intensity. Hemispheres and intensities used were: Pigeon 93, left, 300 μ A; Pigeon 95, right, 300 μ A; and Pigeon 119, right, 200 μ A. It was possible for a bird to obtain continuous stimulation in these reinforcement periods by rapid pecking.

The procedure for concurrent scheduling was similar to that reported by Stubbs and Pliskoff (1969). In the experimental chamber, right key pecks were occasionally followed by food and left key pecks were occasionally followed by brain stimulation. The VI schedules allocating reinforcements to the two keys were not independent. They were arranged on a single two-channel tape timer such that when a reinforcement was set up for one key both tapes stopped until that reinforcement occurred. This procedure precisely controls the relative number of reinforcements available for responding to the two keys.

When an animal commenced responding on one key after responding on the other, reinforcement could not occur until 2 sec had elapsed after the first response. This procedure, known as a changeover delay (Herrnstein, 1961), was used to prevent reinforcements on one key from maintaining responding on the other key (concurrent superstitions).

Stability of performance was assessed as follows. After the first 10 sessions, it was determined each day whether the median relative numbers of responses to one key differed by less than 0.05 from the median of the previous five days. When each animal had individually reached this criterion on five (not necessarily consecutive) days, the experimental conditions were changed.

The birds were exposed to six experimental conditions in which the relative reinforcement rate with respect to food was varied from 0.00 to 1.00. Table 1 shows the sequence of experimental conditions and the number of sessions training given. In all conditions, the number of responses, the number of reinforcements, and the time spent responding on each key

Table 1

Sequence of experimental conditions and number of sessions training under each for all animals.

Condition	Schedule		No. of Sessions		
	Food	Brain Stimulation	No. 93	No. 95	No. 119
1	VII min	VII min	14	14	17
2	VII0 min	VII min	15	19	21
3	VI0.5 min	VII min	14	14	14
4	VI3 min	VII min	15	17	20
5	Extinction	VII min	15	14	18
6	VII min	Extinction	14	14	20

were recorded. Timing for each key commenced when that key was first pecked and continued until the other key was pecked. Experimental sessions of 75 min were conducted daily.

RESULTS

All results (Table 2) are shown as the sums of the three measures (responses, time, and reinforcements to the two keys) over the last five sessions of training under each condition.

Data from each of the last five experimental sessions are shown in Fig. 1 as the logarithm of the ratio of the responses emitted and the time allocated to the food and brain stimulation keys as a function of the logarithm of the ratio of the numbers of reinforcements for the two keys (Baum and Rachlin, 1969). Also shown in this figure are the best-fitting lines by the method of least squares and lines of unit slope with the same constant as the best-fitting lines.

If the animals in the present experiment were allocating responses and time to the two keys according only to the rates of reinforcement obtained on the keys, then the best-fitting lines in Fig. 1 would have unit slope with zero intercept (Baum and Rachlin, 1969). If the animals were matching according to equation (4) with the ratio of the values of the two reinforcers constant, we would expect best-fitting lines of unit slope but displaced from zero intercept by a constant factor ($\log q_1/q_2$) for each animal. The data shown in Fig. 1 clearly support equation (4).

The average time allocation data for the three animals on the log-log coordinates of Fig. 1 give a slope of close to unity with an inter-

Table 2

Responses to food and brain stimulation keys, times (in seconds) spent responding to the two keys, and reinforcements obtained on the two keys. All data are sums of the last five experimental sessions.

Condition	Responses		Time		Reinforcers	
	Food	Brain Stimulation	Food	Brain Stimulation	Food	Brain Stimulation
No. 93						
1	15876	5541	16270	2513	204	207
2	5921	8633	5230	13766	23	229
3	15751	1834	17413	1379	356	176
4	14124	9442	13887	4400	81	242
5	25	4416	45	18327	0	272
6	27310	2	20878	13	358	0
No. 95						
1	11547	3621	12978	5514	221	223
2	1683	2551	2444	17326	18	179
3	12999	2827	14522	3607	422	207
4	7128	4933	9047	9545	79	242
5	19	3216	120	18578	0	234
6	8411	50	20987	100	351	0
No. 119						
1	16708	3214	16437	2355	206	206
2	2392	2721	7312	12633	16	158
3	17475	1122	17842	1141	314	154
4	11764	2956	16243	2626	70	208
5	2	2350	16	20010	0	154
6	13208	0	21153	0	286	0

Fig. 1. The logarithm of the ratio of responses (P_1/P_2) and time (T_1/T_2) on the food and brain stimulation keys as a function of the logarithm of the ratio of the number of reinforcers obtained by responding on the two keys. For individual animals, the data are from the last five sessions of each experimental condition. The lower graphs show the average data for the three animals over these five sessions. The broken lines were fitted to the data points by the method of least squares, and the equation of each regression line appears beside it. The heavy lines have a slope of 1.0 with the same constant as the best-fitting lines. Beneath the equations are shown the mean square deviation of the data points from the best fitting line, and in parentheses the mean square deviation from the line of unit slope.

cept of 5.1 (alog 0.71). The best-fitting lines for each animal taken individually also have slopes of close to unity, although the intercept values range from 1.9 to 6.0. Data on response allocation are less clear. For the three animals taken together, the slope of the best-fitting

line is somewhat less than unity, and this is true also of each animal taken individually. This result indicates a slight preference in response allocation measures for food when the rate of the food reinforcer is low compared to the rate of brain stimulation. For the response data, the average intercept value of the fitted line is 4.5, individuals varying from 3.0 to 7.1.

In all cases, the mean square deviations of the fitted lines for response allocation are less than those for time allocation, indicating a greater variability in the time allocation data. As expected, the mean square deviations of both time and response data from a line with unit slope and the same intercept as the best-fitting line were generally greater than the deviations from the best-fitting line itself. The intercepts of the best-fitting lines for all animals were positive, indicating a consistent preference for the food reinforcer over the brain stimulation reinforcer.

When extinction was scheduled on either key, response and time allocation to that key fell to a very low level (Table 2). These data cannot be shown in Fig. 1 because the logarithm of the ratios of reinforcement would be infinite.

DISCUSSION

Data from the present experiment support equation (4) as a description of the relation between behavior and the rate and type of reinforcement. The support is better for time allocation measures than for response allocation measures, although the variability in the former data were greater than in the latter. The ratio of the values of the two types of reinforcer used appears to remain constant while the rates of the two reinforcers are varied. In the present data, the value of 3-sec access to grain is two to seven times greater than the value of 15-sec access to ectostriatal brain stimulation. Clearly, this statement is not absolute and is in need of modification to take into account other variables such as the exact electrode placements, deprivation levels, and the intensity of brain stimulation. In the present experiment, the animal used with the smallest stimulating current (Animal 119, 200 μA) did have the highest preference for food relative to brain stimulation, as would be expected if the value of ectostriatal stimulation was positively related to current intensity.

Relative preferences for food over brain stimulation reinforcement were not identical for response and time allocation measures in the individual animals. While the reason for this difference is not at present clear, it should be noted that the ordering of the preferences for food reinforcement was similar for both response and time measures. It is left for further experimentation to determine whether response or time allocation measures are most useful in determining relative preference for quantitatively differing reinforcers and (a) whether these two measures do consistently give differing results for q_1/q_2 , and (b) whether the variability in response measures is normally less than that in time measures.

The 2-sec changeover delay, which occurred when an animal switched from responding on one key to responding on the other, was effective in preventing concurrent superstitions. If concurrent superstitions were present, then responding to a key would not cease when reinforcers were no longer delivered following responses to that key. In the present experiment, conditions of extinction on both the brain stimulation and food keys were arranged to assess the presence of concurrent superstitions: in all cases responses to the key under extinction fell to a very low level (Table 2).

The durations of food and brain stimulation used in the present experiment were different. Duration of reinforcement controls the amount of a reinforcer available per reinforcement period and as such is a potent variable in choice (Catania, 1963; Brownstein, 1971). The analysis of the present experiment could have taken account of this by the addition of a further multiplicative term, a_1/a_2 , in equation (4), giving even greater differences between the values of the brain stimulation and food reinforcers per unit time. Such an analysis is not reported for the sake of clarity.

The present experiment unfortunately did not measure bias towards either response key. We are thus unable to say how much key bias would modify our estimates of q_1/q_2 for the individual subjects and for the group. Future research should not neglect this point.

The procedure used in this experiment could no doubt be improved. The use of the Stubbs and Pliskoff non-independent concurrent VI technique does have advantages: it precisely controls the relative numbers of reinforcers delivered for responses on each key,

and it also allows comparison of reinforcers differing vastly in the amount of behavior they maintain by preventing the exclusive choice of one key. But difficulties can, and do, arise. In studying brain stimulation intensity, for example, biases in measurement may be made using this procedure, since it could require an animal to enter a brain stimulation period of zero or even negative value in order to obtain further preferred reinforcers. These conditions could lead to an overestimation of the value of stimulation by low current intensities due to the requirement that the stimulation period be taken in order that further preferred reinforcers be obtained.

Almost all work investigating the effects of brain stimulation placement, intensity, and duration have used single schedule designs. Most often, response rates on a single schedule are used to demonstrate the value of various brain stimulation parameters. This seems particularly unfortunate as single schedule response rates (e.g., on VI schedules) are notoriously insensitive to changes in magnitude of reinforcement (Catania, 1963) and rate of reinforcement (Herrnstein, 1961; Catania and Reynolds, 1968). On the other hand, concurrent VI schedules are highly sensitive to these variables. Although it seems that response rates in single schedules and choice in concurrent schedules are related (Herrnstein, 1970), the most useful quantitative data on reinforcement value are likely to come from the latter. We would therefore like to make a plea for the greater use of concurrent schedules in the study of brain stimulation reinforcement.

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Received: 8 March 1971

(Final Acceptance: 6 July 1971.)