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The Matching Law under Two-key/two-feeder Condition

Tsutomu Taga and Shigeru Watanabe**

Five pigeons were trained in an operant chamber with two keys and two hoppers. Response to either key was reinforced by a brief presentation of the hopper directly below the key. Different values of conc VI-VI schedules were systematically administered and the relative response to each key was found to be functionally related to the relative frequency of reinforcement obtained from each key. Thus, the matching law was confirmed in the two-key/two-feeder situation. However, most of the birds showed a tendency of undermatching and ecological meanings of the undermatching were discussed.

Herrnstein (1961) found that the proportion of responses at an alternative was a function of the proportion of reinforcement obtained from the alternative and named this relationship the "matching law".

$$B1/(B1 + B2) = R1/(R1 + R2) \quad (1)$$

where B1, B2 means rate of responding and R1, R2 rate of reinforcement respectively.

Since then, there have been many confirmations of this phenomenon (Brounstein & Pliskoff, 1968; Herrnstein, 1970; Reynolds, 1963; see also Davison & McCarthy, 1988). Later, this formula was modified to a more general form which describes the ratio of choice as a power function of the ratio of reinforcement (Baum, 1973, 1974a; Baum & Rachlin, 1969; Staddon, 1968).

$$\log(B1/B2) = a \log(R1/R2) + k \quad (2)$$

Although deviation from the generalized matching law in an extreme reinforcer condition was reported (Davison & Jones, 1995), generality of the matching law has been well established. The matching law can be applied to several species including the human being (Baum, 1975, 1976; Liewellen, et al, 1976; Schroeder & Holland, 1969; see also Plaud, 1992). Golden hamsters have a cheek pocket where they keep their earned pellets in an operant chamber and eat them later in their living cages.

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The hamsters also showed the matching law (Furuya et al., 1994). Experimental results using different behavioral measures, such as time spent at an alternative (Baum, 1979), and different kinds of reinforcement (Miller, 1976) supported the generality of the matching law.

Animals' behavior in an operant chamber can be regarded as foraging behavior comparable to that in natural situations. The matching law itself has been applied to natural situations (for example, Baum, 1974b). From such a point of view, choice behavior under concurrent schedules can be considered as a choice between food sites which require an animal different costs to get the food. One possible difficulty in such a comparison is the number of operanda and food hoppers in one operant chamber. The most common apparatus for concurrent schedule consists of two or more operanda and one feeder. In other words, two or more different foraging behaviors produce feed in spatially the same place. There has been no report on a multiple operanda/multiple feeder arrangement. In the present experiments, the authors arranged two food hoppers associated with two pecking keys respectively and analyzed choice behavior under concurrent schedules.

METHOD

Subjects

Subjects were pigeons (*Columba livia*), maintained at 80% of their free-feeding weights. They had a history of operant conditioning with a single key.

Table 1. Sequence of conc VI-VI trainings. The number in the first line indicates the value of the VI schedule for the left/right keys. The number in each cell and that in parentheses represent the order of conditions and the number of sessions.

Sub	Value of Concurrent Schedule						
	EXT/1.5	9.0/1.8	4.5/2.25	3.0/3.0	2.25/4.5	1.8/9.0	1.5/EXT
1	7 (13)	1 (17)	2 (15)	6 (19)	3 (24)	4 (12)	5 (13)
2	7 (37)	1 (19)	2 (13)	6 (32)	3 (23)	4 (17)	5 (32)
3	5 (14)	4 (13)	3 (19)	6 (20)	3 (22)	1 (15)	7 (64)
4	5 (34)	4 (7)	3 (40)	6 (13)	2 (17)	1 (19)	7 (14)
5	7 (30)	2 (14)	1 (15)	6 (34)	3 (70)	5 (23)	5 (14)

Apparatus

The experimental chamber was a large operant chamber (50×50×40 cm), modified to attach two response keys and two feeders. The two keys (diameter=3 cm) and the two feeders were placed on a front panel. Each key could be illuminated by a 24 V miniature bulb. The distance between the keys was 4.5 cm and the distance from the floor to the keys was 27.5 cm. An opening for the grain hopper (8×6 cm) was placed below each key. The reinforcement consisted of 3-sec access to mixed grain in the hopper. The experiment was arranged by a microcomputer system (Apple 2).

Procedure

At first pigeons were trained to peck either key by alternately covering one key. Then they were trained with both keys simultaneously. Two VI schedules were effective on two keys (conc VI-VI) independently and a pecking response emitted on one key less than 2-sec after a peck to the other key was not effective to produce reinforcement (COD 2'). This conc VI 3'-VI 3' training continued until the subjects showed a steady responding rate to both keys. One daily session lasts for 60 min. The value of the VI schedule for each key was changed to the next one in accordance with Table 1.

The value was changed to the next one when the birds showed fewer than 10 pecks difference in total responses per min for 3 successive sessions. The minimum number of each condition is 7 sessions and the maximum is 70 sessions. Data of the last three sessions in each condition were used for analysis.

RESULTS

The number of sessions for each training condition is given in Table 1. Figure 1 presents individual results obtained from the last 3 sessions in each condition.

A linear-regression analysis was calculated according to Baum's analysis (1974a). Two of the subjects showed a slight tendency of overmatching (C-11, C-21), but the others clearly showed undermatching (A-32, C-12, C-22). The coefficient of correlation (Spearman's) was above .90 for every subject.

The linear regression analysis for all subjects' data is shown in Figure 2.

The mean of 44 pigeons' data collected by Baum (1979) is also presented in Figure 2.

DISCUSSION

The present results clearly confirmed the matching law under two-key/two-feeder conditions. One interesting point is that three of five subjects showed undermatching. Undermatching was shown by 117 out of 137 pigeons whose individual data has been published (Baum, 1974a, and Wearden & Burgess, 1982). Thus, separation of feeders in our experiment might reduce the tendency of undermatching. Because of the small number of our subjects, however, it is premature to conclude that the effect was due to feeder separation. Undermatching itself has been observed in a majority of the published data not only by from pigeons, but also rats (Norman & McSweeney, 1978), and cows (Mathew & Temple, 1979).

Undermatching seems to depend on the index of behavior. Rate of responding, which is the most common index of operant behavior, tends

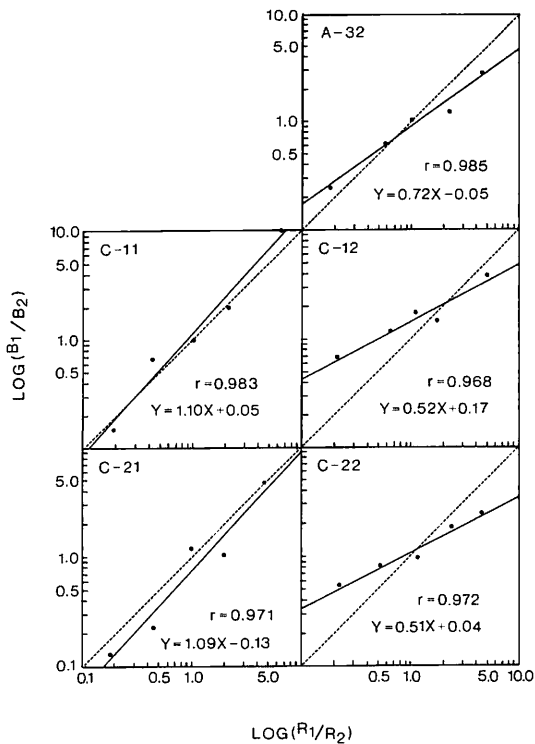


Figure 1. Logs of the ratios of the overall rates of responding under (B1/B2), and logs of the ratios plotted as a function of the logs of the ratios overall rates of reinforcement obtained from the components (R1/R2). Data from five pigeons are shown. Each point is the mean of the values generated over the last three sessions for which each schedule was presented. The least square lines (solid lines) and their equations are given. The broken lines represent the matching relation. The parameter r gives the coefficient of correlation. Two of the subjects show slight overmatching (C-11, C-21), and the others show a clear tendency of undermatching (A-32, C-12, C-22).

to give a value of "a" (in formula 2) of less than 1.00, whereas time allocation, which is another index, tends to give a value of "a" more close to 1.00. Gray (1994) observed substantial undermatching in an aviary experiment with a flock of sparrows and suggested a factor of social rank in the matching law observed in group

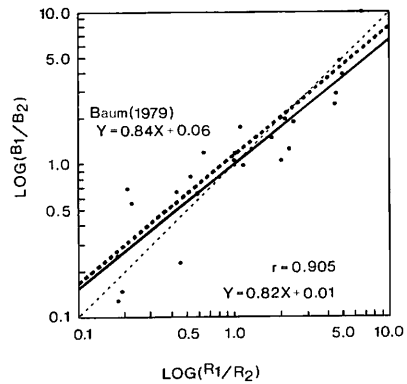


Figure 2. Comparison of the present data and previously reported data. The solid line represents the present results (five pigeons) and the thick broken line the mean of 44 equations collected by Baum (1979). The thin broken line shows complete matching.

foraging.

Another factor contributing to undermatching may be confusion of two operants. In fact, the length of the COD, which should affect discriminability of the two operants, also affects the value of "a" (Baum, 1974a). However, enhancing the discriminability of the two operants by coloring the two keys (Leisland, 1979) or employing two different types of operant (Davison & Fergusson, 1978; Wheatley & Engberg, 1978) did not result in complete matching but rather undermatching. The present experimental two-key/two-feeder arrangement had been also expected to enhance the discriminability of the two operants.

Undermatching seems to violate the optimality principle, because the animal responds at poor site relatively more often than rate of reinforcement correlates. In other words, the animal buys food at a higher price at the lower reinforcement rate site while it can buy the same food for a lower price at the higher reinforcement rate site.

What causes such apparently maladaptive behavior? One possible explanation is based on separation of short-term adaptation and long-term adaptation. Complete matching represents short-term adaptation. It also agrees with the optimality principle at least in the case of conc

VI-VI. If we consider natural conditions, we can imagine that any feeding site should have a risk of depletion. So, if an animal consumes all of its food from one feeding site, depletion of it must cause severe starvation of the animal. On the other hand, if the animal distributes its feeding behavior to more than one feeding site, sudden depletion of one feeding site can be compensated by supply from another site. Therefore, distributing feeding behavior to a less promising site with some cost should be an adaptive behavior from the viewpoint of long-term adaptation, even though it looks maladaptive from a short-term adaptation view. Such an explanation of undermatching can get support from a field study. Houston (1986) studied foraging behavior of wagtails for three years. This bird forages in a flock but also forages in its own territory. He measured searching time and rate of prey-catching in the two foraging styles and found undermatching and bias for the territory foraging. Usually flock foraging produced more food than territory foraging, but the territory is the only place where the bird can find food in winter time. So, continuing foraging in territory is adaptive in term of long-term adaptation. Other field studies also support undermatching (Holling, 1959; Smith & Dawkins, 1971).

In summary, undermatching was obtained in a two-key/two-feeder situation. It supports the generality of undermatching in choice of foraging behaviors, and the undermatching can be explained by long-term adaptation.

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