Effects of food deprivation and food reward on the behavior of rats in the radial-arm maze

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The present study examined the effects of food-deprivation and food-reward on the behavior of rats in the eight-arm radial maze. In the free-choice training, all of the four groups of rats, deprived-and-rewarded (DR), deprived-and-unrewarded (DU), nondeprived-and-rewarded (NR), and nondeprived-and-unrewarded (NU), made choice more efficiently than chance level, but the rats in DR made fewer errors than the other three groups. As for the choice patterns, all the groups showed the tendency to choose the arms 90° apart from the arms chosen just before. This tendency was shown most significantly in DR. These findings suggest that the efficient arm-choice behavior of rats is not determined by a simple effect of either food-deprivation or food-reward but by an interactive effect of these two factors.

Key words: rats, radial-arm maze, food-deprivation, food-reward.

Previous studies of spatial memory processes and foraging behavior of rats in the radial-arm maze have reported that the animals readily learn to make efficient choices and that their successive arm choices are not organized systematically but made almost randomly. As pointed out by Olton (1979), food-deprived and rewarded animals performed almost perfectly (choosing about 7.9 different arms in the first eight choices) without any sequential pattern or algorithm after about 40 trials in an eight-arm version of this kind of maze. These results suggest that efficient choice may depend on the excellent spatial memory, and also on the innate foraging strategy, especially on “win-shift” strategy (Olton, 1978).

In most of these experiments, animals were deprived of food and fed food pellets placed at the end of each arm. Their arm choice, therefore, has been considered as the food-seeking behavior motivated by hunger drive.

Some studies, however, have shown that rats’ behavioral efficiency in the arm choice was not affected by presence of the food reward. Walker and Olton (1979) examined the effect of food reward on the performance of food-deprived rats and concluded that the reward did not have important influence on their arm choice. Using a six-arm Dashiell maze and a modified radial-arm maze, FitzGerald, Isler, Rosenberg, Oettinger, and Bättig (1985) reported that the performance of unrewarded rats was not distinguishable from that of rewarded rats, whether they were deprived or not. They suggested that the efficient arm choice in these mazes depended not on the presence or absence of food reward but on the “spontaneous patrolling,” a tendency of avoiding recently-visited arms and searching unvisited arms.

On the other hand, Timberlake and White (1990) argued that rats in the radial-arm
maze showed a response pattern which was caused solely by food deprivation. Their deprived-and-unrewarded animals entered different arms in the first eight choices more frequently than chance level, but nondeprived-and-unrewarded animals did not show the performance above chance level. A related finding was also obtained in the Foreman’s study with food-deprived rats (1985). He indicated that arm choice of rats in the radial-arm maze was not made randomly but was systematically patterned: Many of the rats showed a tendency to enter the arms apart by a certain angle from the arm just chosen, irrespective of the changes in test environment, for example, by maze rotation. He concluded that a flexible interaction between spatial memory and motor response pattern produced the efficient choice of arms.

All of these findings strongly suggest that “win-shift” strategy, “spontaneous patrolling” tendency, and systematically organized “response pattern” play important roles in rats’ apparently efficient choice in the radial-arm maze. However, the consistent results have not so far been obtained with the effects of food deprivation and food reward on the arm-choice behavior.

The present study aimed to examine multiple effects of food deprivation and food reward on the behavior of rats in the eight-arm radial maze. Four groups differing in deprivation / reward conditions (deprived-and-rewarded, deprived-and-unrewarded, nondeprived-and-rewarded, and nondeprived-and-unrewarded) were tested in the free-choice procedure and their performance was compared. In order to compare the response patterns among the four groups, angles between two successively chosen arms were measured. If the same performance level and response pattern are shown in all the groups, it could be inferred that the efficient arm-choice behavior is not caused by either food deprivation or food reward.

Method

Subjects

Twenty-eight experimentally naive male Wistar rats were used as subjects. They were approximately 70 days old at the beginning of the experiment. Two weeks before the start of pretraining, they were assigned to four groups (seven for each): deprived-and-rewarded (DR), deprived-and-unrewarded (DU), nondeprived-and-rewarded (NR), and nondeprived-and-unrewarded (NU). They were housed individually under 12:12 LD cycles. For the rats in the two deprived groups (DR and DU), amount of daily food was restricted to maintain their body weight at about 85% of their ad-lib weight throughout the experiment. These two groups were fed just after daily training. The rats in the two nondeprived groups (NR and NU) were not deprived of food. Water was available from water bottles at any time.

Apparatus

A flat-gray wooden eight-arm radial maze, elevated 50 cm above the floor, was used. The apparatus consisted of a central octagonal platform (30 cm in diameter) and eight arms (50 cm long and 10 cm wide) radiating from the platform at equal angle. The platform and arms were floored with white plastic boards, so that the whole maze could be cleaned completely after each trial. Each arm was surrounded by transparent plastic wall (5 cm high), and additional walls (20 cm high) extending 12 cm from the platform were attached to each arm to prevent rats from jumping from arm to arm. A small plastic food cup (1 cm in diameter and 0.5 cm in depth) was attached 2 cm from the end of each arm. A white plastic guillotine door (20 cm high and 9 cm wide) was installed between the platform and each arm, with an wooden frame (40 cm high). They could be
raised with the pulley-and-string system which was operated at 150 cm away from the maze. The maze was placed in the experimental room measuring approximately 2 m (W) × 4 m (L) × 2.5 m (H). The room was illuminated by two fluorescent tubes from 2 cm above the platform and provided with various extra-maze cues.

**Procedure**

Pretraining and the subsequent test trials were carried out during last three hours in the light phase every day. Pretraining was given for five days before the test. During this period all the rats were habituated to the apparatus and only the rats in the two rewarded groups (DR and NR) were trained to eat the 45 mg pellets (Holton Industries Company), which were also used in the test. Each rat was first placed on the platform and allowed to run around the whole maze without any pellet for 20 minutes per day. After 20 minutes elapsed, all the guillotine doors were closed and the rats in the two rewarded groups were confined in the platform on which about 30 pellets were scattered. They were then allowed to eat pellets for five minutes. For the two unrewarded groups (DU and NU), pellet-eating training was not given. After this pretraining, all the rats were given free-choice test for 15 consecutive days, one trial per day. Before each trial, one pellet was placed in each cup for DR and NR, but no pellet was placed for DU and NU. The trials were started with placing a rat on the platform with the direction of its head altered on each trial. After 10 seconds, all the doors were raised and the rat was allowed to enter freely with time limit of 15 minutes. Arm-entry was counted when a rat put their four paws on an arm and passed the half point of the arm. The rats in DR and NR were required to consume eight food pellets, and those in DU and NU groups were required only to run to the ends of different eight arms. When each trial was over, all the doors were lowered and the rats were immediately returned to the home cages. Then the daily allotment of food was given to the rats in the two deprived groups (DR and DU).

**Data Analysis**

Three measures to compare the performance of four groups were as follows: (a) Correct choices — the number of entries to different arms in the first eight choices of a trial. (b) Errors — the number of re-entries to the arms which were chosen before at least once in a trial. (c) Arm-choice angles — the angle between two successively chosen arms. Repeated choice of the same arm was defined as 0°. Choice of the adjacent arm was defined as 45°. Likewise, choice of an arm with two, three, and four arms apart were defined as 90°, 135°, and 180°, respectively.

**Results**

From the first trial, all the rats in the four groups made more than eight choices: those in DR and NR consumed eight food pellets and those in DU and NU entered eight different arms within 15 minutes. Figure 1 shows the mean number of correct choices per trial.
(7.07 in DR, 6.81 in DU, 6.79 in NR, and 6.63 in NU) and errors per trial (1.68 in DR, 2.89 in DU, 2.95 in NR, and 2.82 in NU). Because the mean numbers of correct choices in all the groups were above the chance level (5.61) estimated by Eckerman (1980), it is clear that each group performed accurately. Two-way analysis of variances (deprivation x reward) showed that main effects of two factors were not significant (p>.05).

The same designed ANOVA was carried out for the mean number of errors. The main effect of deprivation (F(1,24)=4.58, p<.05) and the interaction (F(1,24)=4.64, p<.05) were significant. Tests for simple main effects as post-hoc analysis of the interaction detected significant differences of deprivation between the two rewarded groups, DR and NR, (F(1,24)=9.22, p<.01) and of reward between the two deprived groups, DR and DU, (F(1,24)=8.34, p<.01). These results indicate that DR made significantly fewer errors than the other three groups.

To illustrate arm-choice patterns, angles of the two successive choices in 15 trials were analyzed (912 choices in DR, 1 037 in DU, 1 046 in NR, and 1 029 in NU). Figure 2 shows the distribution of the arm-choice angles. Because of infrequent occurrence of 0° choices (zero in DR, three in DU and NU, and five in NR), the frequency of this angle was excluded from the analysis. This figure clearly shows that all the groups made choices of 90° arms more frequently than any other angles, and that DR group made more number of 90° choices than the other three groups (53.8% in DR, 37.8% in DU, 37.9% in NR, and 34.8% in NU).

To confirm these, firstly, the distribution of the arm-choice angles of each group was compared with the expected distribution. This expected distribution was obtained with a simple response bias commonly observed, namely, a very few occurrence of re-entering the arm just visited (Olton & Samuelson, 1976). In calculation, the probability of successively repeated choices was excluded and the occurrence of choices to the remaining seven arms was treated as random. Thus the expected probability of each arm-choice angle was 0% in 0°, 28.57% in 45°, 90°, 135°, and 14.29% in 180°, respectively. Chi-square tests revealed that the choice distributions for the four groups were significantly different from the expected one (χ²(3)=135.94 in DR, 20.55 in DU, 24.46 in NR, and 17.49 in NU, p<.01).

Then, with respect to the frequency of 90° choice which was the highest in all the groups, two-way ANOVA (deprivation x reward) was carried out. The main effects of deprivation (F(1,24)=11.08, p<.005) and reward (F(1,24)=11.52, p<.005) and the interaction (F(1,24)=4.69, p<.05) were significant. Tests for simple main effects detected significant differences of deprivation between the two rewarded groups, DR and NR, (F(1,24)=15.10, p<.005) and of reward between the two deprived groups, DR and DU, (F(1,24)=15.46, p<.005). These results indicate that DR made 90° choices more frequently than the other three groups.

Figure 2. Distribution of the arm-choice angles for each group.
Discussion

The findings of the present experiment demonstrated that four groups of rats performed more efficiently than chance level, and that the deprived-and-rewarded group made fewer errors than the other three groups. With respect to arm-choice angles, each group tended to choose 90° arms apart from just-chosen ones more frequently than the other angles, and this tendency was most distinct in the deprived-and-rewarded group.

Although deprived and rewarded rats are generally used in radial-arm maze experiments, the present results suggest that even if these rats can perform efficiently, it is hard to attribute their high level of performance only to their excellent spatial memory. Rather, there should be some mixture of response patterning and spatial memory especially in the case of the free-choice training which does not prevent sequential choices.

As for the interactive effects of deprivation and food reward on the performance of rats, Timberlake and White (1990) found that deprived rats, whether rewarded or not, traversed the radial maze efficiently and they ascertained that major determinants of superior maze behavior were irrelevant to food reward. The results of the present experiment, on the other hand, showed that deprived-and-rewarded rats made significantly fewer errors than deprived-and-unrewarded ones. This suggests that presence of food reward can affect the performance of deprived rats. Moreover, both of the two nondeprived groups made almost the same number of correct choices as the two deprived groups. This also suggests that undeprived rats can make arm choice as efficiently as deprived ones. These findings are obviously incompatible with those of Timberlake and White (1990), in that the latter showed the difference in choice performance between the deprived-and-unrewarded group and the nondeprived-and-unrewarded group.

With respect to this discrepancy, several ideas from Cowan (1977) may be useful. He considered the behavior of rats in the maze as "patrolling", which means the behavior of moving around their environment regularly and attending to any changes occurred in it. He also presented the results showing that the patrolling behavior did not decline even after repeated exposures in the residential maze and was scarcely affected by deprivation or food reward. Other studies (Uster, Bättig, & Nägeli, 1976; Bättig & Schlatter, 1979; Gaffan & Davies, 1982) also pointed out the systematic patrolling behavior of unrewarded rats. It might be, then, inferred that this patrolling behavior played a major role of increasing the arm-choice efficiency not only in the deprived rats (DR and DU) but also in the nondeprived ones (NR and NU).

The significant difference in the number of errors between deprived-and-rewarded and deprived-and-unrewarded rats, however, still remains unexplained. If the efficient choices were caused solely by patrolling behavior, there should be no group differences. One possibility to explain this result would be to assume that associative learning played a subsidiary role in reducing errors for deprived-and-rewarded rats. If it is the case, the food-rewarded experience associated with entries to unvisited arms would promote avoiding re-entries and making systematical choices, which result in reducing errors and specifying choice patterns.

In summary, the findings presented here pointed out that food-deprivation and food-reward had interactive effects on rats' choice behavior in the radial-arm maze. Also those suggest that their choice behavior can hardly be explained only by their spatial learning.
References


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