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Research article

Behavioral representation of cost and benefit balance in rats

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HIGHLIGHTS

- Rats acquire the rule of "Do more, get more" after training.
- Rats adopt different most cost-effective strategy when faced with different cost-benefit ratios.
- There exists a "balance point" of cost and benefit in the valuation system of rats.

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ABSTRACT

Decision making is dependent upon individual motivation. Previous studies showed that animals with higher levels of motivation are more likely to invest more time to acquire larger rewards rather than acquiring smaller rewards with less time to wait. However, little is known about how this motivation mediates the cognitive effort animals devote upon making said decisions in detail. In the present study, we investigated the behavioral response in a goal-directed action under a differential reward schedule by training rats to perform a "Do more, get more" (DM-GM) task using a nosepoke operandum when longer nosepoke durations resulted in correspondingly larger rewards. In general, the subjects learned this DM-GM rule and reached a steady behavioral state within 15 days. During the training stage, the rats found the most cost-effective action choice and behaved according to that guideline more frequently than other possible actions. In addition, when the cost-benefit ratio changed, the rats again found a new most cost-effective choice to obtain maximum rewards. Our results demonstrate that there is a "balance point" of cost and benefit in rat valuation system and that this "balance point" not only guides the rats to make the appropriate decision, but that this point can be modified upon new situations to choose a newer optimum action plan.

1. Introduction

Decision making refers to the process that humans and animals use to choose between competing courses of action based on the expected costs and the relative outcome values of each choice. These costs may involve the risk that a reward may not be forthcoming, the investment of time or effort, and are also regulated by the internal state of the subject [5,8,13,23]. Selecting an action from a set of available options on the basis of an evaluation of the potential costs and benefits is a fundamental brain function for both humans and animals [11,18].

The majority of previous studies on cost-benefit decision making used behavioral models that required decisions between two competing response choices that are explicitly associated with rewards of distinct value. In those studies, there were either small reward amounts and large reward amounts or the use of nonpreferred and preferred rewards [1,22]. For example, T-maze tasks have been used where the preferred reward may only be accessed by climbing over a barrier [3,6,7,11,12,16,28]. An alternative method entails a choice between a smaller reward obtainable by devoting minimal effort (e.g. a single lever press) and a larger or more palatable reward accessible only after investing a greater effort (e.g. many lever presses on a fixed- or progressive-ratio schedule) [4,8,20,24,25,29]. However, few studies have investigated cost-benefit decision choices while subjects are able to freely decide the energy or time expenditure on free-running trials [9].

Substantial work in recent years has shown that there is a valuation system in the brain [10,15,17,19]. In choosing between different options, the brain computes the value of stimulus inputs and the cost of action that is generated by each action. Following that, it integrates them into action values given by this simple equation: action value = stimulus value − action cost. Finally, a decision is made by comparing these action values [2,21,26]. When the potential benefit is lower than the expected cost, animals will

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choose to give up the pursuit of a large reward with long-term waiting or greater effort and instead choose a small reward which they could get immediately [14,27]. Therefore, a "balance point" of cost and benefit may exist in the valuation system of humans and animals to help individuals decide whether to carry on or give up a choice.

The current study aimed to find this "balance point" by employing a behavioral paradigm called the "Do more, get more" (DM–GM) task. The rats sustained a nosepoke for various durations in order to obtain a reward. By maintaining longer nosepokes, which inherently involve more cognitive effort via the inhibition of the natural tendency to withdraw, subjects earned greater rewards. During the training stage with a certain cost-benefit ratio, rats tended to maintain nosepokes for a specific duration (i. e. the most cost-effective choice). When the cost-benefit ratio was changed, they changed that duration, so they could find a new most cost-effective choice to get an adequate reward for their time. Our results revealed that there is a "balance point" of cost and benefit that exists in the valuation system of rats and that when faced with different cost-benefit situations, this "balance point" will also change for each situation.

2. Materials and methods

2.1. Subjects

Thirty-four, 5-week-old male Sprague-Dawley rats weighing 140–160 g were used as subjects. They were randomly grouped and individually housed at 21 °C in a 12 h light/dark cycle (lights on at 7:00) climate-controlled vivarium, and experiments were conducted between 9:00 and 17:00. All rats were handled, 5 min/day/rat, for 7 days before the training began. Water was restricted to ~85% of their ad libitum body weight gradually following the handling process. During the experiment period, every subject was free to drink for 10 min after they carried out daily tasks, and their body weights were monitored daily to ensure a steady weight loss during water restriction. All procedures were conducted in accordance with the *Guiding Principles for the Care and Use of Laboratory Animals* (NIH, 1996). All experiments were approved and monitored by the Ethical Committee of Animal Experiments at the Institute of Life Science, Nanchang University.

2.2. Behavioral apparatus

The subjects were trained in the apparatus showing in Fig. 1A. The DM-GM arena was a custom-made gray plastic chamber (70 cm × 25 cm × 25 cm) with an open top. One panel of the chamber had a semicircular hole (2.5 cm diameter) which was 10 cm above the floor and had an infrared nosepoke entry detector. The opposite end of the chamber was equipped with an infrared beam to detect the arrival of subjects at the reward receptacle where a solenoid valve delivered the water reward. Once a subject arrived at the reward receptacle, the infrared beam would be interrupted, which activated the valve and appropriate water would be delivered to the reward receptacle immediately. The apparatuses were controlled by in-house software.

2.3. Behavior protocol

2.3.1. Pre-training stage 1

A group of three or four water restricted rats were placed in the chamber and were allowed to explore freely. Once a subject probed its nose into the nosepoke hole for more than 30 ms, accompanied with a slight tone with gradually increasing frequency, the apparatus would deliver 100 μl water instantly which would be recorded as one correct trial. The training program was constantly repeated until every subject averagely completed 64 trials. Once a subject could probe its nose into the hole and turn back to drink water immediately, it would be introduced to the next stage.

2.3.2. Pre-training stage 2

This stage was exactly the same as the first stage except that subjects were placed in the chamber individually. This was carried out to ensure that each subject could complete a minimum of 64 trials every day. They would be transferred to the next training stage once they reached this criterion for two consecutive days.

2.3.3. Training

In this stage, the rat was required to probe its nose into the nosepoke hole and stay for at least 800 ms. Once a subject withdrew its nose from the hole, it must move to the opposite end of the chamber within 5 s to get water. The volume of the water delivered was directly proportional to the nosepoke duration, i.e., longer nosepoke duration maintained by the subject equaled a larger reward delivered (Fig. 1B and C). Each subject was allowed to perform 64 trials every day.

2.3.4. Testing

In this stage, subjects had to change their nosepoke maintenance duration strategy in order to get the maximum expected reward according to the different cost-benefit ratios. Every session contained four 20-trial blocks that pseudorandomly appeared. If a subject nosepoked for the same time in different blocks, they could earn either 100%, 75%, 50%, or 25% of the normal volume of water (Fig. 1B and C). Once a subject finished 20 trials of one block, the program would automatically switch to another block until the subject completed all four blocks.

2.3.5. Performance criteria

Rats that reached the following two criteria were considered to be subjects with stable performance: 1) its success rate (the percentage of successful trial in a session) had to be above 85% for three consecutive days; 2) all main task variables, including success rate, single-attempt rate (the percentage of successful trials with a single-attempt nosepoke) and locomotion time (the time between nose withdrawal and reward delivery) had to show no significant differences for at least three consecutive days.

2.4. Data analysis and statistics

All behavioral data were statistically analyzed by using SigmaPlot (Systat software, San Jose, CA) or MATLAB (MathWorks, Natick, MA). All variables are expressed as the mean ± SEM in every case. For the training stage, the main task variables across different days were tested with 1-way ANOVA with the post hoc Least Significant Difference test to determine whether performance improved and reached a steady state. For the testing stage, the Kolmogorov-Smirnov test (K-S test) was used to compare the cumulative performance at different cost-benefit ratios.

The delay index was calculated as follows:

$$Delayindex = \frac{P_t}{\delta \times R}$$

P_t is the actual performance, δ is the reciprocal of cost-benefit ratio, and R is the reward quantity at 100% reward. The delay indexes at different cost-benefit ratios were compared using paired t-test.

We fitted behavior data with the Gaussian function, which was calculated as follows:

$$f_{(x)} = \alpha \times e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$