



Relatively high motivation for context-evoked reward produces the magnitude effect in rats



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ABSTRACT

Using a concurrent-chain schedule, we demonstrated the effect of absolute reinforcement (i.e., the magnitude effect) on choice behavior in rats. In general, animals' simultaneous choices conform to a relative reinforcement ratio between alternatives. However, studies in pigeons and rats have found that on a concurrent-chain schedule, the overall reinforcement ratio, or absolute amount, also influences choice. The effect of reinforcement amount has also been studied in inter-temporal choice situations, and this effect has been referred to as the magnitude effect. The magnitude effect has been observed in humans under various conditions, but little research has assessed it in animals (e.g., pigeons and rats). The present study confirmed the effect of reinforcement amount in rats during simultaneous and inter-temporal choice situations. We used a concurrent-chain procedure to examine the cause of the magnitude effect during inter-temporal choice. Our results suggest that rats can use differences in reinforcement amount as a contextual cue during choice, and the direction of the magnitude effect in rats might be similar to humans when using the present procedure. Furthermore, our results indicate that the magnitude effect was caused by the initial-link effect when the reinforcement amount was relatively small, while a loss aversion tendency was observed when the reinforcement amount changed within a session. The emergence of the initial-link effect and loss aversion suggests that rats make choices through cognitive processes predicted by prospect theory.

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1. Introduction

Choice during simultaneous situations matches the relative reinforcement ratio between alternatives; this relationship is referred to as the matching law (Herrnstein, 1961) or the generalized matching law (Baum, 1974). This law states that relative reinforcement ratios are equal between two choice situations as long as the ratio is the same. For example, the degree of response matching will be equal in a situation where a rat must choose one of two levers that issue either 1 or 2 pellets and in a situation where the levers issue 10 or 20 pellets; in other words, the difference in overall reinforcement amount does not affect the response matching.

However, some studies have reported an effect of overall reinforcement amount during simultaneous choice situations among pigeons (Alsop and Elliffe, 1988; Fantino, 1969; Fantino et al., 1972; Fantino and Davison, 1983) and rats (Uchida and Ito, 2000). These studies suggest that increases in the number of reinforcements

per unit time enhance preferences for the alternative, which has a higher reinforcement amount than the other alternative. These results are consistent with the prediction that the more food there is, the more feeding becomes selective. This is based on optimal foraging theory (Charnov, 1976). However, Logue and Chavarro (1987) reported a case among pigeons where an increase in the overall reinforcement amount changes preferences into non-preferences. This finding is in contrast to results observed in other choice studies as well predictions from optimal foraging theory.

During inter-temporal choice situations, relative reinforcement ratios are also thought to be equal between two choice situations as long as the delay is the same. For example, when rats must choose between levers that issue pellets after a 1-s or 5-s delay, it will not matter how many pellets the rats receive – if they choose the 1-s delay, the degree of response matching will be the same whether they receive 1 or 10 pellets; the same is true of the 5-s delay. This is because the simplest model of temporal discounting (shown in Eq. (1)) assumes that the delay universally discounts the reinforcement value regardless of the total amount.

$$V = \frac{A}{1 + KD} \quad (1)$$

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V , subjective value of the reward; A , amount of reward; D , delay; K , free parameter.

However, experiments using human subjects revealed that the difference in absolute reinforcement amount affects this discounting. This effect is known as the magnitude effect: the larger the absolute amount of reinforcement, the smaller the discount rate caused by the delay (Green et al., 2004) and vice versa. This effect tends to be caused by both a virtual (Benzion et al., 1989; Green et al., 1997, 1999; Myerson and Green, 1995; Raineri and Rachlin, 1993; Thaler, 1981) and real reward (Johnson and Bickel, 2002; Kirby, 1997; Kirby and Maraković, 1996). Furthermore, not only the absolute reinforcement amount but also the quality of reinforcement produces the same effect (Estle et al., 2007).

Conversely, there are still questions as to whether the magnitude effect emerges during inter-temporal choice for non-human animals. For instance, there is no evidence of the magnitude effect in monkeys (Freeman et al., 2009). In pigeons, negative (Grace, 1999; Green et al., 2004) and positive (Ong and White, 2004; Grace et al., 2012) findings are both reported, but the direction of the effect reported in Ong and White (2004) was opposite to that observed in humans. Thus, firm conclusions cannot be drawn at this point. The magnitude effect observed in humans and pigeons (Grace et al., 2012) is contrary to predictions from the optimal foraging theory explained above. In rats, Wogar et al. (1992, 1993) and Orduña et al. (2013) reported that smaller amounts of reinforcement decreased the discount rate; therefore, the effect's direction was opposite to that observed in humans and pigeons (Grace et al., 2012) but the same as reported by Ong and White (2004). Saeki et al. (2002) reported a tendency toward the magnitude effect in rats. The direction was the same as that observed in humans, but Green et al. (2004) reported an absence of the magnitude effect in rats. Moreover, differences in the quality of reinforcement had no effect on behavioral preferences in monkeys (Freeman et al., 2012) and rats (Calvert et al., 2010).

One reason for the inconsistent results regarding the existence of the magnitude effect in animals, regardless of the effect's direction, could be attributed to procedures used in previous experiments. Except for Grace et al. (2012) and Orduña et al. (2013), the aforementioned animal experiments all applied either the "adjusting delay" (Mazur et al., 1987) or the "adjusting amount" procedures (Green et al., 2004). Conversely, the adjusting amount procedure has solely been used in human experiments (Rachlin et al., 1991). In these procedures, two simultaneous alternatives are typically used. One is an adjusted delay (or amount) alternative, and the other is a standard delay alternative. The length of delay inserted before reward presentation for the adjusted alternative in the adjusting delay procedure (or the number of rewards in the adjusting amount procedure) is gradually changed based on the subject's choice until the alternative is selected as much as the standard alternative.

These procedures do have a few limitations. First, the standard alternative provides less uncertainty than the adjusting alternative since the reward delay (or amount) changes across trials for the adjusted alternatives. Thus, there remains the possibility that differences in uncertainty between alternatives may affect the response ratio. Second, it seems dubious that animals can change their choice according to the subjective value of an adjusted alternative, which is adjusted based on only a few trials. Such properties in these adjusting procedures might mask the magnitude effect in animal experiments. In fact, Ong and White (2004), Grace et al. (2012) and Orduña et al. (2013) reported that the magnitude effect emerged in pigeons and rats when using the concurrent-chain procedure, not the adjustment procedure. Thus, using a suitable procedure for animal studies may produce results that are more positive.

Based on the issues outlined above, the present study employed the concurrent-chain procedure. Moreover, we inserted an interval according to the delay difference occurring before the reward presentation. This was done to make sure each alternative was equal in terms of overall component length, which follows from Grace et al. (2012). Orduña et al. (2013) did not correct for the difference in inter-trial interval caused by the terminal-link (TL) difference delay between alternatives. This occurred because, regardless of delay length, the next trial uniformly started 3 s post-reinforcement.

Based on these considerations, we designed a concurrent-chain procedure for rats. We confirmed the effect of reward amount on the relative response ratio when delay was controlled between alternatives (Experiment 1) and when delay was not controlled during an inter-temporal choice situation (Experiment 2). We then examined the cause(s) of the magnitude effect during inter-temporal choice.

2. General method

2.1. Animals and apparatus

All experiments were performed in accordance with guidelines from the Animal Experiment Committee of the University of Tokyo. Four adult male Long-Evans rats were used in this experiment. Water was available ad libitum, but food was restricted to maintain approximately 85% ($\pm 2.5\%$) of the rats' free feeding weight. The weight of one pellet used as reinforcement was 0.05 g. All experiments and recordings were conducted in an experimental chamber (ENV-009L, Med Associates, Vermont, USA) placed in a soundproof box (Muromachi Kikai, Tokyo, Japan).

2.2. Procedure

The concurrent-chain procedure consists of an initial-link (IL) and terminal-link (TL). Completion of the IL leads to the initiation of the TL, and the completion of the TL produces reinforcement. During the IL, two levers were simultaneously presented, and subjects could respond to both levers for a variable period of time. Our procedure used only one clock during the IL, so our ILs were not independent. When the IL was completed, the session proceeded to the TL.

When proceeding from the IL to the TL, both levers were retracted, and then one lever, pre-determined by the experimenter, was presented. For all subjects in Grace et al. (2012) and half of the subjects in Orduña et al. (2013), the Fixed interval (FI)-schedule was used during the TL. However, this could have caused confusion between the actual delay and the programmed delay before the presentation of reinforcement. Therefore, in the present experiment, a Fixed time (FT)-schedule was used, as was the case for half of the subjects in Orduña et al. (2013). The pre-determined lever was presented to signal the start of the delay. Response to this lever started the delay, and the lever was immediately retracted. After the delay, the lever was again presented, and response to this lever was reinforced. The total number of reinforcements was equated between the levers, and the experimenter coded the switch from the IL to the TL regardless of a subject's preference during the IL. In general, this procedure is likely to bias a choice towards the non-preferred alternative, but this procedure also controls the number of reinforcements between alternatives (Stubbs and Pliskoff, 1969).

The relative response ratio to one lever during the IL is used as an index of preference for that lever. Note that subjects might change their preference for one lever during the IL by reinforcement given during the TL, even if the relative response ratio during the IL did not affect the reinforced lever during the TL. After one week of handling, five days of habituation to the chamber, and one day

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