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# Concurrent progressive-ratio schedules: Built-in controls in the study of delayed reward efficacy

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ABSTRACT

*Background:* Delayed rewards maintain lower rates of operant responding than immediate rewards, and when given a choice between immediate and delayed rewards, individuals typically choose the immediate reward, even when it is smaller (a phenomenon called delay discounting). The behavioral and neural mechanisms underlying these behavioral patterns, however, are not conclusively understood. The present study developed a method to examine the efficacy of delayed rewards in a way that is suitable for pharmacological manipulation of delayed reward efficacy (while controlling for general changes in reward efficacy).
*New method:* The progressive ratio (PR) paradigm often used to examine reward efficacy was modified such that two PR schedules for lever pressing concurrently yet independently were presented. Across a series of conditions, a range of delays (3–81 s) were arranged on one of the levers while the reward on the other lever remained immediate.
*Results:* PR breakpoints (the highest ratio completed on each lever, our measure of reward efficacy) systematically decreased on the delayed, but not on the immediate reward lever, suggesting that delays decreased reward efficacy. This decrease in breakpoint resulted in bias in within-session responding that was accounted for by models that adjusted reward value by the delay to that reward.
*Comparison with existing methods:* Unlike the standard PR paradigm, the present arrangement provided the controls needed to differentiate delay specific from general changes in reward efficacy.
*Conclusions:* The present method should be helpful in the study of the behavioral and neural mechanisms of delayed reward efficacy. Modifications of the present paradigm should be useful for pharmacological studies.



## 1. Introduction

Delayed rewards tend to maintain lower rates of responding than immediate rewards (e.g., Jarmolowicz and Lattal, 2013; see Lattal, 2010, for a review), and when organisms are given a choice between a smaller yet immediate and a larger yet delayed reward, the propensity to choose the larger reward decreases as the delay to its receipt increases (see Bickel et al., 2012; Cardinal, 2006, for reviews). The consistency of this effect across experimental preparations and the prevalence of disordered patterns of responding for delayed rewards across a range of clinical populations (e.g., drug addiction, gambling, obesity, ADHD, etc.; see Bickel et al., 2012 for a review) have spurred considerable interest in the neural mechanisms associated with responding for delayed rewards (e.g., Cardinal, 2006; Koffarnus et al., 2013).

One possibility is that delayed rewards may maintain lower rates of responding and be non-preferred because they are less efficacious than immediate rewards. If this is the case, rate/choice independent markers of reward efficacy should be lower for delayed relative to immediate rewards. Over the past 50 years, progressive ratio (PR) schedules have come to be widely used as a response rate-independent measure of the efficacy of drug (see Richardson and Roberts, 1996; Stafford et al., 1998, for reviews) and non-drug rewards (e.g., Hodos, 1961). On a PR schedule, the number of responses required for each successive reward systematically increases, with the highest requirement completed (called the breakpoint) providing an index of reward efficacy. To examine the relation between reward efficacy and delays, Jarmolowicz and Lattal (2011) exposed pigeons to PR schedules both with and

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without delayed rewards (delays ranged from 1 to 20 s). Breakpoints (i.e., the highest ratio completed) decreased as the delays to the reward increased, suggesting that the efficacy of the delayed rewards was lower than that of the immediate rewards.

Although the Jarmolowicz and Lattal (2011) study provided evidence that delays may decrease the efficacy of rewards, several limitations restrict its utility as a baseline in the study of variables thought to impact delayed reward efficacy (e.g., methamphetamine; Pitts and Febbo, 2004). First, the PR was only active for one response. If responding during one of the delay conditions was used as a baseline for the administration of a pharmacological compound, changes in motivation for delayed rewards would be indistinguishable from general changes in motivation. The concurrent assessment of the efficacy of non-delayed rewards would allow for separate analysis of delay-specific (i.e., delay lever) and general (non-delay lever) changes in motivation. Second, due to the length of the delay conditions in the Jarmolowicz and Lattal study (e.g., 13–31 days), it is possible that overall fluctuations in motivation were spuriously captured. Although the Jarmolowicz and Lattal study conducted extensive replications to control for this possibility, the concurrent assessment of the efficacy of non-delayed rewards would provide a higher level of control (Sidman, 1960). And third, the Jarmolowicz and Lattal study examined the efficacy of delayed rewards in pigeons. Demonstration of similar effects in rodents would facilitate examination of genetic differences in motivation (e.g., obese vs lean Zucker rats, SHR vs. WKY rats, etc.).

The current experiment evaluated a baseline that could be used to examine effects of various pharmacological/therapeutic regimens on the efficacy of delayed rewards. Specifically, effects of various delays were examined on one lever of an independent concurrent progressive ratio schedule in rats. The concurrent assessment of the efficacy of non-delayed rewards in each experimental phase provided a reference point by which delay-specific versus general changes in motivation can be assessed.

## 2. Method

### 2.1. Subjects

Four male Sprague Dawley rats obtained from Charles River (Raleigh, NC) maintained on a 22-h deprivation schedule were used in the present experiments. Rats had access to food during the experimental sessions and for the remainder of the 2 h access period beginning approximately 15 min after session. Rats were fed in pairs but were monitored and fed individually in cases wherein dominance relations developed. The rats were housed in pairs, were 162–166 days old at the beginning of the experiment, and had previous experience on schedules of reinforcement. Water was freely available in the home cages, located in a colony room where a 12 h:12 h light–dark cycle was maintained. All sessions were conducted during the light phase on the light–dark cycle. All of the current procedures were in accordance with the guidelines established by the University of Kansas Institutional Animal Care and Use Committee.

### 2.2. Apparatus

Sessions occurred in standard operant conditioning chambers (30.5 cm long, 24.1 cm wide, 21.0 cm high; Med Associates, Inc., St. Albans, VT). Centered on the front wall, 1 cm above the floor grid was a pellet receptacle (3 cm × 4 cm) into which a pellet dispenser could dispense grain based pellets (45 mg; Bio-Serv, Frenchtown, NJ). Retractable levers were positioned on either side of the pellet receptacle (11 cm apart; 5 cm from the floor). A 28-V DC cue light was positioned 2 cm above each lever, and a 28-V houselight centered on the back wall (19 cm from the floor) provided general illumination. Chambers were housed in sound attenuating cubicles with fans to mask extraneous noise. All experimental events were programed and recorded using MED-PC IV software (MED Associates, Inc. & Tatham, 1991) controlled by a PC.

### 2.3. Procedure

Sessions occurred 6–7 days a week at approximately the same time each day and ended after the rats ceased responding for 300-s. Because the rats had previous experience responding on schedules of reinforcement, pre-training procedures were not needed.

At the beginning of each session, the houselight was turned on and both of the response levers were inserted into the chamber. Rats responded on independent concurrent progressive ratio schedules. Specifically, the ratio requirement on each lever began at a fixed ratio (FR) 10 and increased by 10 following each reinforcer. The schedules operated independently, thus completing a ratio on one lever did not impact the ratio requirement on the other lever. Completing the ratio requirement on either lever resulted in a reinforcer consumption period which included a brief tone (0.1 s), the delivery of a food pellet, and the levers being retracted for 5-s. The houselight remained on during these reinforcer consumption periods. The temporal relation between the completion of the ratio requirement and the reinforcement consumption period varied across conditions, as is described below.

During the *baseline* condition, completing a ratio requirement on either of the two levers resulted in the immediate initiation of a reinforcer consumption period. Baseline conditions were conducted for at least 13 sessions and until responding on both levers was stable. Stability was defined by examining BPs over the final six sessions of the phase. If the mean BP over the first three sessions (of the final six sessions) and the last three sessions did not differ by more than 6%± from the mean BP over the final six sessions, and there was no visual evidence of a monotonic trend, data were deemed stable. The data from each of the two levers had to be stable before a phase change could be initiated.

During the *delay* conditions, completing a ratio requirement on the right lever still resulted in the immediate initiation of reinforcer consumption period, whereas completing a ratio requirement on the left lever resulted in a signaled delay wherein the levers were retracted for *x*-s prior to the reinforcer consumption period. The value of *x* increased across conditions (i.e., 3, 9, 27, and 81-s; the 9 s delay condition was omitted for 1R3, and the 27 s condition was omitted for 1G3), and each delay condition was separated by a return to the baseline condition. Each delay condition was conducted for at least 13 sessions and until responding on both levers was stable. Stability was defined the same way as it was in the baseline conditions.

### 2.4. Data analysis

Effects of delay were primarily assessed on an individual basis. This individualized analysis occurred at two levels – mean breakpoints for each condition (Fig. 1) and a behavioral economic analysis of patterns of ratio completion across the two response alternatives (Fig. 2). Mean breakpoints were calculated based on the final six sessions of each delay condition (note, baseline breakpoints calculated from a total of final six sessions from all baseline conditions).

The behavioral economic analysis (Fig. 2) examined responding during the final six sessions of each delay condition. Specifically, a model based on unit price (UP; Hursh et al., 1988), *UP = Fixed ratio*/*Pellets*, predicted that rats would complete whatever ratio requirement was lower at that moment. This would yield a predictable pattern of switching between the two levers (solid line,