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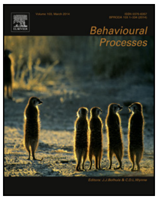

Concurrent progressive ratio schedules: Effects of reinforcer probability on breakpoint and response allocation

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ABSTRACT

Although progressive ratio (PR) schedules have been used to explore effects of a range of reinforcer parameters (e.g., magnitude, delay), effects of reinforcer probability remain underexplored. The present project used independently progressing concurrent PR PR schedules to examine effects of reinforcer probability on PR breakpoint (highest completed ratio prior to a session terminating 300 s pause) and response allocation. The probability of reinforcement on one lever remained at 100% across all conditions while the probability of reinforcement on the other lever was systematically manipulated (i.e., 100%, 50%, 25%, 12.5%, and a replication of 25%). Breakpoints systematically decreased with decreasing reinforcer probabilities while breakpoints on the control lever remained unchanged. Patterns of switching between the two levers were well described by a choice-by-choice unit price model that accounted for the hyperbolic discounting of the value of probabilistic reinforcers.

1. Introduction

On a progressive ratio (PR) schedule, reinforcers are delivered after the subject completes a specified ratio requirement which increases following each reinforcer delivery. Sessions terminate following a pause of a predetermined duration (Hodos, 1961; Jarmolowicz and Lattal, 2010). The highest completed ratio prior to session termination, called the breakpoint (BP), is often seen as a somewhat response-rate independent measure of reinforcer effects (Stafford et al., 1998). Progressive ratio BPs are positively related to reinforcer parameters such as reinforcer concentration (Spear and Katz, 1991; Hodos, 1961), volume (Spear and Katz, 1991; Hodos, 1961; Hodos and Kalman, 1963; Rickard et al., 2009), and duration (Hodos, 1965).

Although prior studies have explored the impact of various reinforcer parameters, the relation between PR BP and the probability of ratio completion resulting reinforcer delivery remains underexplored. Given that an extensive literature on probabilistic choice has demonstrated that preference for probabilistic rewards decrease rapidly as the probability of receiving those rewards decreases (see Green and Myerson, 2004; for a discussion) and clinical populations such as problem gamblers (Madden et al., 2009) often overvalue probabilistic rewards, the sparseness of the literature on the efficacy of probabilistic reinforcers limits our understanding of clinically significant behavioral processes. In a notable exception, Kirkpatrick et al. (2014) examined BPs for probabilistic and certain reinforcers as part of their examination of behavioral effects of environmental rearing conditions. In their study, BPs were collected for two sessions at each of three probabilities (i.e., 100%, 67%, and 17%) in a fixed order. Breakpoints systematically decreased as the probability decreased, suggesting a positive relation between probability and BP. Methodological details of the Kirkpatrick et al. (2014) study, however, limit some of the conclusions that could be made. First, rats received limited exposure to each condition (i.e., 2 sessions), reducing the likelihood that stable data was obtained. This may be particularly problematic in early sessions as the rats acclimate to respond on PR schedules. This lack of steady state data may be particularly problematic because sessions were run in a fixed order, potentially confounding effects of transition to steady PR responding with effects of systematically decreasing reinforcer probabilities. Second, no control condition and or reversals were conducted to assure that the decreased PR BPs were due to the schedule manipulations, rather than other history effects (e.g., schedule acclimation). Despite these limitations, the Kirkpatrick et al. (2014) study suggests that relations between BP and probability of reinforcement warrant further study.

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The current study builds from the Kirkpatrick et al. (2014) study by conducting a steady state analysis (addressing the possibility that Kirkpatrick et al., examined PR BPs that were still in transition) of PR BPs at baseline and at three reinforcer probabilities (i.e., 50%, 25%, and 12.5%). Reinforcer probabilities remained at baseline levels on a second PR schedule, providing a concurrent control condition (addressing Kirkpatrick et al.'s lack of a control condition) and allowing for the analysis of effects of reinforcer probability on within-session patterns of response allocation (cf. Jarmolowicz and Hudnall, 2014).

2. Method

2.1. Subjects

Four male Long-Evans rats obtained from Charles River (Raleigh, NC) maintained on a 22-h deprivation schedule were used in the present experiments. The rats were housed in pairs, were approximately 45 days old at the beginning of the experiment, and had previous experience lever pressing under a different schedule of reinforcement (i.e., tandem FR1 DRO 17.5 s). 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 X 4 cm) into which a pellet dispenser could dispense grain-based pellets (45 mg; Bio-Serv, Frenchtown, NJ). Retractable levers requiring approximately 5 g of force to operate 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. Each chamber contained a Sonalert tone generator. 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 (Tatham and Zurn, 1989) 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 no pre-training procedures were used.

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 PR PR schedules. Specifically, the ratio requirement on each lever began at a fixed ratio (FR) 5 and increased by 5 following each reinforcer. The schedules operated independently, thus completing a ratio on one lever did not impact the ratio requirement or responses accumulated toward 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 scheduled pellet deliveries, and both levers being retracted for 5 s. The houselight remained on during these reinforcer consumption periods. The probability with which these consumption periods scheduled pellet delivery upon ratio completion on the test lever was manipulated across conditions, as described below.

During the *baseline* condition (16 sessions for wp1, 14 for wp2, seven for pw1, and 18 for pw2), completing a ratio requirement on either of the two levers resulted in pellet delivery during the reinforcer consumption period. Baseline conditions were conducted 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 3 sessions (of the final 6 sessions) and the last 3 sessions did not deviate from the mean BP over the final 6 sessions by more than 10%, and there was no visual evidence of a monotonic trend, data were deemed stable.

During the *probabilistic* conditions, completing a ratio requirement on the right lever still resulted in pellet delivery during the reinforcer consumption period, whereas completing a ratio requirement on the left lever resulted in reinforcer consumption period wherein there was an x % chance of a reinforcer being delivered. Reinforcer delivery was determined by randomly (without replacement) selecting yes or no from a list of eight values. The value of x decreased across conditions (i.e., 50, 25, 12.5, and a replication of 25), and each probabilistic condition was conducted until responding on both levers was stable (defined as in the baseline condition). Rat wp1 required seven sessions at $x = 50$, 12 at $x = 25$, 15 at $x = 12.5$, and 26 at the $x = 25$ replication. Rat wp2 required nine sessions at $x = 50$, 12 at $x = 25$, 20 at $x = 12.5$, and 20 at the $x = 25$ replication. Rat pw1 required seven sessions at $x = 50$, 17 at $x = 25$, 15 at $x = 12.5$, and 20 at the $x = 25$ replication. Rat pw2 required 10 sessions at $x = 50$, nine at $x = 25$, 26 at $x = 12.5$, and 13 at the $x = 25$ replication.

3. Results

Fig. 1 shows the mean BP during each condition on the probabilistic (closed circles) and certain (open circles) levers with the error bars showing one SEM. Breakpoints on the probabilistic lever systematically decreased as the odds against receiving a reinforcer increased. A similar decrease was not observed for responding on the (certain) control lever. This pattern was observed in each of the four rats yet a slight decrease in control lever responding was also observed for the rat pw1. For three of the four rats (cf. wp1) this general pattern of results was obtained during the return to the 25% probability condition.

Next, within-session patterns of response allocation were modeled and plotted. For this analysis, the unit price (UP),

$$UP = \frac{FR}{A}, \tag{1}$$

for responding on the certain lever was plotted on the x-axis, and the mean FR on probabilistic ratio when that certain lever UP was completed was plotted on the y-axis. For this model, A is the amount of reinforcement and FR is the required ratio requirement. Predictions of two models of UP with probabilistic reinforcers were compared to these obtained data. First, the Hursh et al. (1988) model,

$$UP = \frac{FR}{AxP} \tag{2}$$

which adjusts the benefit portion of the cost/benefit ratio by probability (P) of reinforcement, and a novel model,

$$UP = \frac{FR}{V}, \tag{3}$$

which replaces A with value (V) from Rachlin et al., 1991. This yields a new equation,

$$UP = \frac{FR}{\left[\frac{A}{1+h\theta}\right]} \tag{4}$$

wherein the given amount (A) of a reinforcer is adjusted by the rate at which that reinforcer is discounted (h) and the odds against