

*CHOICE WITH CERTAIN AND UNCERTAIN REINFORCERS IN
AN ADJUSTING-DELAY PROCEDURE*

JAMES E. MAZUR

SOUTHERN CONNECTICUT STATE UNIVERSITY

A discrete-trials adjusting-delay procedure was used to investigate the conditions under which pigeons might show a preference for partial reinforcement over 100% reinforcement, an effect reported in a number of previous experiments. A peck on a red key always led to a delay with red houselights and then food. In each condition, the duration of the red-houselight delay was adjusted to estimate an indifference point. In 100% reinforcement conditions, a peck on a green key always led to a delay with green houselights and then food. In partial-reinforcement conditions, a peck on the green key led either to the green houselights and food or to white houselights and no food. In some phases of the experiment, statistically significant preference for partial reinforcement over 100% reinforcement was found, but this effect was observed in only about half of the pigeons. The effect was largely eliminated when variability in the delay stimulus colors was equated for 50% reinforcement conditions and 100% reinforcement conditions. Idiosyncratic preferences for certain colors or for stimulus variability may be at least partially responsible for the effect.

Key words: reinforcement probability, reinforcement delay, conditioned reinforcers, choice, key peck, pigeons

When animals choose between certain and uncertain reinforcers, they often show less preference for the certain reinforcer than might be expected on logical grounds. For example, consider a situation in which a subject makes a choice response, waits 5 s, and then there is a 20% chance that food will be delivered (so this can be called the 20% alternative). In a case like this, Rachlin, Logue, Gibbon, and Frankel (1986) proposed that a subject should be willing to wait five times as long for an alternative that delivered a reinforcer on 100% of the trials (the 100% alternative), because on average, it will take five trials with the 20% alternative before a reinforcer is delivered. However, in a series of experiments, Mazur (1989, 1991; Mazur & Romano, 1992) found that pigeons would not wait nearly as long for a certain reinforcer as the Rachlin et al. theory suggested. For instance, in one condition, Mazur (1989) found that a reinforcer delivered after a 5-s delay on 20% of the trials was about equally preferred

to a certain reinforcer delayed 17 s (whereas the average delay to food would be 25 s for the 20% alternative, even if the intertrial intervals were not included).

To account for these results, Mazur (1989) proposed that delivering a reinforcer with a probability of less than 1 is similar to delivering a reinforcer after a variable delay. The 20% alternative described above might deliver a reinforcer after 5 s (i.e., on the first trial it is chosen), or after 10 s (on the second trial), and so on. To predict when such an uncertain reinforcer would be chosen over a delayed certain reinforcer and when it would not, Mazur used the hyperbolic decay model:

$$V = \sum_{i=1}^n P_i \left(\frac{1}{1 + KD_i} \right), \quad (1)$$

where V is a reinforcer's value (its ability to sustain choice responses), P_i is the probability that a delay of D_i seconds will occur between a choice response and the delivery of the reinforcer, and K is a free parameter. In previous articles, this equation was used to make predictions for situations in which reinforcers were delivered on every trial after a delay (e.g., Mazur, 1984, 1986). To apply this same equation to probabilistic reinforcers, Mazur (1989) proposed that D_i does not include the total time between a choice response and the delivery of the reinforcer, but only the time

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Correspondence concerning this article should be sent to James E. Mazur, Psychology Department, Southern Connecticut State University, New Haven, Connecticut 06515.

spent in the presence of conditioned reinforcers—stimuli that precede the delivery of food. In the Mazur (1989, 1991) studies, the two choice alternatives were represented by red and green keylights, and red and green houselights were present during the delays for the two alternatives. Mazur proposed that the colored keylights and houselights were the conditioned reinforcers, and that for each choice alternative, D_i should include the total time spent in the presence of its conditioned reinforcers before food was delivered.

For example, consider the case in which a peck on the red key led to a 5-s delay with red houselights, and then food was delivered on 20% of the trials. Response latencies were about 1 s, so the red keylight was lit for about 1 s on each trial. For instance, when food was delivered on the first choice of the red key, D_i was 6 s (1-s red keylight plus 5-s red houselights). Similarly, D_i was 12 s if food was delivered on the second choice of the red key (two trials with 1-s red keylights and 5-s red houselights), D_i was 18 s if food was presented on the third choice, and so on. Using Equation 1, each value of D_i was weighted by its probability of occurrence, P_i , to estimate the overall value, V , of this uncertain reinforcer. Equation 1 was then used a second time to estimate the delay for a 100% alternative that would be equally preferred to the uncertain alternative. Using an adjusting-delay procedure to measure indifference points, Mazur (1989, 1991) found that the hyperbolic decay model made reasonably successful predictions for choices between certain and uncertain reinforcers.

This model predicts that the total durations of the conditioned reinforcers are critical determinants of the value of an uncertain reinforcer, and several lines of evidence have supported this notion. For example, Mazur (1989, 1991) found that if the colored houselights were not present during the delay periods on nonreinforced trials, decreasing the reinforcement percentage had very little effect on choice. This result is predicted by the model because although no food was presented on nonreinforcement trials, the conditioned reinforcers (colored houselights) were not presented either, so D_i was not increased, and V was not decreased. Mazur (1995) took this reasoning one step further and showed that, in certain cases, with the

appropriate arrangement of houselight colors and durations, the model predicts that subjects should actually choose a 50% alternative over a 100% alternative. The experimental results supported this counterintuitive prediction.

Although these results were consistent with the hyperbolic decay model, other cases in which a 50% alternative was preferred over a 100% alternative pose a problem for the model (Belke & Spetch, 1994; Dunn & Spetch, 1990; Kendall, 1974, 1985; Spetch, Belke, Barnet, Dunn, & Pierce, 1990; Spetch, Mondloch, Belke, & Dunn, 1994). For example, in Experiment 3 of Dunn and Spetch (1990), each choice of the 100% alternative led to a 50-s delay signaled by a single key color, then food. Each choice of the 50% alternative led to a 50-s delay signaled by one of two different key colors, and then food was presented on 50% of the trials. In unsignaled conditions, the key colors for the 50% alternative were not correlated with food presentations (i.e., either color might or might not be followed by food), and subjects always showed a strong preference for the 100% alternative. This result is consistent with the hyperbolic decay model, because the average time in the presence of the conditioned reinforcers before a food delivery was longer for the 50% alternative. However, in signaled conditions, one key color for the 50% alternative was always followed by food and the other was never followed by food. In these conditions, 2 or 3 of the 5 pigeons showed a preference for the 50% alternative, despite its lower probability of reinforcement. The other studies cited above provided additional examples of signaled conditions in which some subjects preferred the 50% alternative over the 100% alternative. Dunn and Spetch proposed a modified version of Fantino's (1969) delay-reduction theory in an effort to account for these results.

For such signaled conditions, the hyperbolic decay model predicts either indifference or a slight preference for the 100% alternative, not preference for the 50% alternative. Only one of the two stimuli for the 50% alternative is associated with food, so the other cannot be considered to be a conditioned reinforcer, and its duration is not included as part of D_i . If only the stimuli that precede food are counted, then D_i is the same for both the 50%

and 100% alternatives, so the model predicts indifference. If the brief time spent in the choice period is included as part of D_i (as was done in the studies of Mazur, 1989, 1991, 1995), then D_i will be slightly longer for the 50% alternative, so the model predicts a slight preference for the 100% alternative. Notice that the rate or frequency of presentation of the conditioned reinforcer is not included as a variable in Equation 1, except insofar as changing the rate of presentation might change the values of D_i or P_i .

Although these results showing a preference for the uncertain alternative seem to present a problem for the hyperbolic decay model, their significance can be questioned for several reasons. In the earliest study, Kendall (1974) used an unusual arrangement of stimuli that may have affected the outcome (see Fantino, Dunn, & Meck, 1979). In other studies, there were often very large individual differences, with some subjects showing strong preference for the 50% alternative and others showing strong preference for the 100% alternative (Belke & Spetch, 1994; Dunn & Spetch, 1990; Spetch et al., 1990). Some of the studies did not control for key color or position biases, which might have contributed to the large individual differences (Dunn & Spetch, 1990; Spetch et al., 1990, 1994). Two studies (Belke & Spetch, 1994; Kendall, 1974) controlled for position biases but not for color biases. The possibility of position or color biases is of particular concern because in most of the studies, subjects chose between the two alternatives by making a single key peck. With minimal response requirements, a slight position or color bias might have resulted in near-exclusive preference for one alternative or the other. Finally, preference for the 50% alternative has been found only under certain conditions (with very brief choice periods, and no delays to the onset of the conditioned reinforcers); otherwise, subjects showed indifference or a preference for the 100% alternative (Belke & Spetch, 1994; Dunn & Spetch, 1990).

The results of these studies, especially the individual differences, may be difficult to interpret, but the puzzling preference for partial reinforcement over 100% reinforcement is certainly in need of further investigation. The present experiment was designed to obtain additional information about this phe-

nomenon by using an adjusting-delay procedure similar to the one used in Mazur's previous studies (1989, 1991, 1995). In this procedure, subjects chose between a standard alternative and an adjusting alternative. The standard alternative delivered food on a schedule that remained constant throughout an experimental condition. The adjusting alternative delivered food after a delay that was adjusted over trials so as to estimate an indifference point—a delay at which both alternatives were chosen about equally often. Indifference points provide straightforward and easily interpreted measures of the strength of a subject's preference. Thus if a subject exhibits a preference for the 50% alternative, the indifference point can indicate whether this preference is a weak or strong one. Furthermore, this procedure controlled for position and color biases, because both the 50% and 100% alternatives were presented, in turn, as the standard alternative, and the same key color and position were used for both.

To determine how preference for the uncertain reinforcer (if any) varied as a function of reinforcement percentage, this experiment used two additional reinforcement percentages (20% and 80%). Finally, the experiment examined the possible role of stimulus variability in choices between certain and uncertain reinforcers.

METHOD

Subjects

The subjects were White Carneau pigeons maintained at approximately 80% of their free-feeding weights. The 4 pigeons in Part A had served in the experiment of Mazur (1995) that used similar procedures, and Part A began immediately after the end of that experiment. Subject 1 died at the end of Part A, and 4 additional pigeons were added to the experiment at that time, so a total of 7 pigeons served in Parts B and C. All pigeons had previous experience with a variety of experimental procedures, and required no pre-training for this experiment.

Apparatus

Two similar chambers were used. Each was 30 cm long, 30 cm wide, and 32 cm high. Three response keys, each 1.8 cm in diame-

ter, were mounted in the front wall of each chamber, 23 cm above the floor. A force of approximately 0.1 N was required to operate each key, and every effective response produced a feedback click. Each key could be transilluminated with lights of different colors. A hopper below the center key provided controlled access to mixed grain, and when grain was available, the hopper was illuminated with a 2-W white light. Eight 2-W lights (two white, two red, two green, and two orange) were mounted above the wire-mesh ceiling of each chamber. Each chamber was enclosed in a sound-attenuating box containing a ventilation fan. All stimuli were controlled and responses recorded by an IBM®-compatible personal computer using the Medstate® programming language.

Procedure

Part A (Conditions 1 through 6). In Conditions 1, 3, and 5 (the 50% conditions), the standard alternative delivered reinforcers on a random half of the trials. In Conditions 2, 4, and 6 (the 100% conditions), the standard alternative delivered reinforcers on every trial.

All sessions lasted for 64 trials or for 60 min, whichever came first. Each block of four trials consisted of two forced trials followed by two choice trials. Figure 1 shows the possible sequences of events that could occur on choice trials in the 100% conditions. At the start of every trial, the center key was illuminated with white light, the white houselights were on, and a single peck on the center key was required to begin the choice period. The purpose of this center peck was to make it more likely that the subject's head was equidistant from the two side keys when the choice period began. A peck on the center key darkened this key and illuminated both the left green key and the right red key. Throughout the experiment, the green key represented the standard alternative and the red key represented the adjusting alternative.

A peck on the green key extinguished both side keys and initiated a delay of either 10 s or 30 s, during which the green houselights were lit. The delays were chosen on a random basis, with the constraint that every 16 trials with the standard alternative included eight instances of each delay. At the end of the standard delay, the green houselights were extinguished and grain was presented for 3 s.

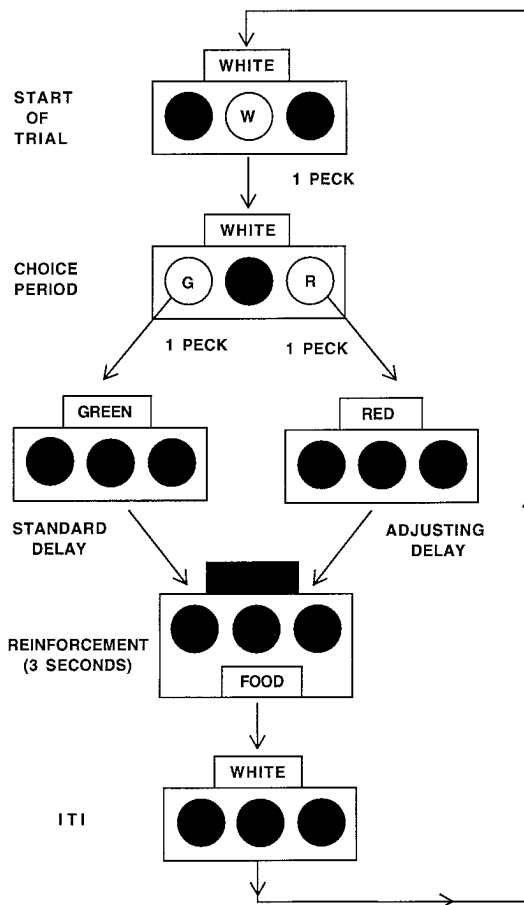


Fig. 1. The sequences of events that could occur on a choice trial in the 100% conditions of Part A, depending on whether the red or green key was pecked during the choice period.

The mixture of two delays, 10 s and 30 s, was used for two reasons. First, the pigeons had received extensive exposure to this mixed-delay procedure in the immediately preceding experiment (Mazur, 1995). Second, if a preference for the 50% alternative was found, this would extend the generality of this phenomenon to choices involving variable delays to reinforcement.

A peck on the red key during the choice period extinguished both side keys and initiated the adjusting delay, during which the red houselights were lit. The duration of the adjusting delay was changed over trials, as explained below. At the end of the adjusting delay, the red houselights were extinguished, and grain was presented for 3 s. For both the

standard and adjusting alternatives, only the white lights above the grain were lit during reinforcement periods. After each reinforcement period, there was an intertrial interval (ITI) during which only the white houselights were lit. The duration of the ITI was adjusted so that the total time from the choice response to the end of the trial was 50 s in all conditions, for both the standard and adjusting alternatives.

The procedure on forced trials was the same as on choice trials, except that only one side key was lit, red or green, and a peck on this key led to the appropriate delay. A peck on the opposite key, which was dark, had no effect. Of every two forced trials, one involved the red key and the other the green key. The temporal order of these two types of trials varied randomly.

At the start of each new condition, the adjusting delay was set at 0 s. After every two choice trials, the delay for the adjusting key might be changed. If a subject chose the adjusting key on both choice trials, the adjusting delay was increased by 1 s, up to a maximum of 45 s. If the subject chose the standard key on both trials, the adjusting delay was decreased by 1 s. If the subject chose each key on one trial, no change was made in the adjusting delay. In all three cases, this adjusting delay remained in effect for the next block of four trials. At the start of the next session, the adjusting delay was determined by the above rules as if it were a continuation of the preceding session.

The procedure in the 50% conditions was exactly the same, except that only 50% of the standard trials, selected randomly, ended in reinforcement (half of these after a 10-s delay and half after a 30-s delay). On the other 50% of the standard trials, a peck on the green key extinguished both side keys and initiated a 50-s ITI, during which the white houselights were lit.

All conditions lasted for a minimum of 14 sessions, and were terminated for each subject individually when several stability criteria were met. To assess stability, each session was divided into two 32-trial blocks, and for each block the mean delay on the adjusting key was calculated. The results from the first two sessions of a condition were not used, and a condition was terminated when the following criteria were met, using the data from all sub-

sequent sessions: (a) Neither the highest nor the lowest single-block mean of a condition could occur in the last six blocks of the condition. (b) The mean adjusting delay across the last six blocks could not be the highest or the lowest six-block mean of the condition. (c) The mean delay of the last six blocks could not differ from the mean of the preceding six blocks by more than 10% or by more than 1 s (whichever was larger). (d) Visual inspection showed no large and systematic trends over the last six blocks.

Part B (Conditions 7 through 16). The procedure was the same as in Part A, with the following exceptions. The delay (with green houselights) between the choice response and food on reinforced standard trials was always 20 s. In different conditions, the percentage of reinforced standard trials was varied from 100% to 20%. The reinforcement percentage was 100% in Conditions 7, 12, and 16, 80% in Conditions 11 and 13, 50% in Conditions 8, 9, and 15, and 20% in Conditions 10 and 14. As in Part A, on nonreinforced standard trials, a peck on the green key led to a 50-s ITI with white houselights, except in Condition 8 (which will be called the 50% green condition). In that condition, all choice responses on the green (standard) key led to a 20-s delay with green houselights, but 50% of these delays were followed by food and 50% were not. As in Part A, the duration of the ITI with white houselights was set on each trial so that the total time from a choice response until the start of the next trial was 50 s.

Part C (Conditions 17 through 20). These conditions were included to determine the effects of varying the houselight colors during the delays in similar ways in 100% and 50% conditions. Conditions 18 and 20 were 50% conditions in which there was a 20-s delay with green houselights before the food and the ITI on reinforced standard trials and a 20-s delay with orange houselights before the ITI on nonreinforced standard trials. Conditions 17 and 19 were 100% conditions in which there was a 20-s delay before food on all standard trials, but the houselight color during the standard delays was green on a random half of the trials and orange on the other half.

These conditions examined the possibility that variability in the stimuli following a

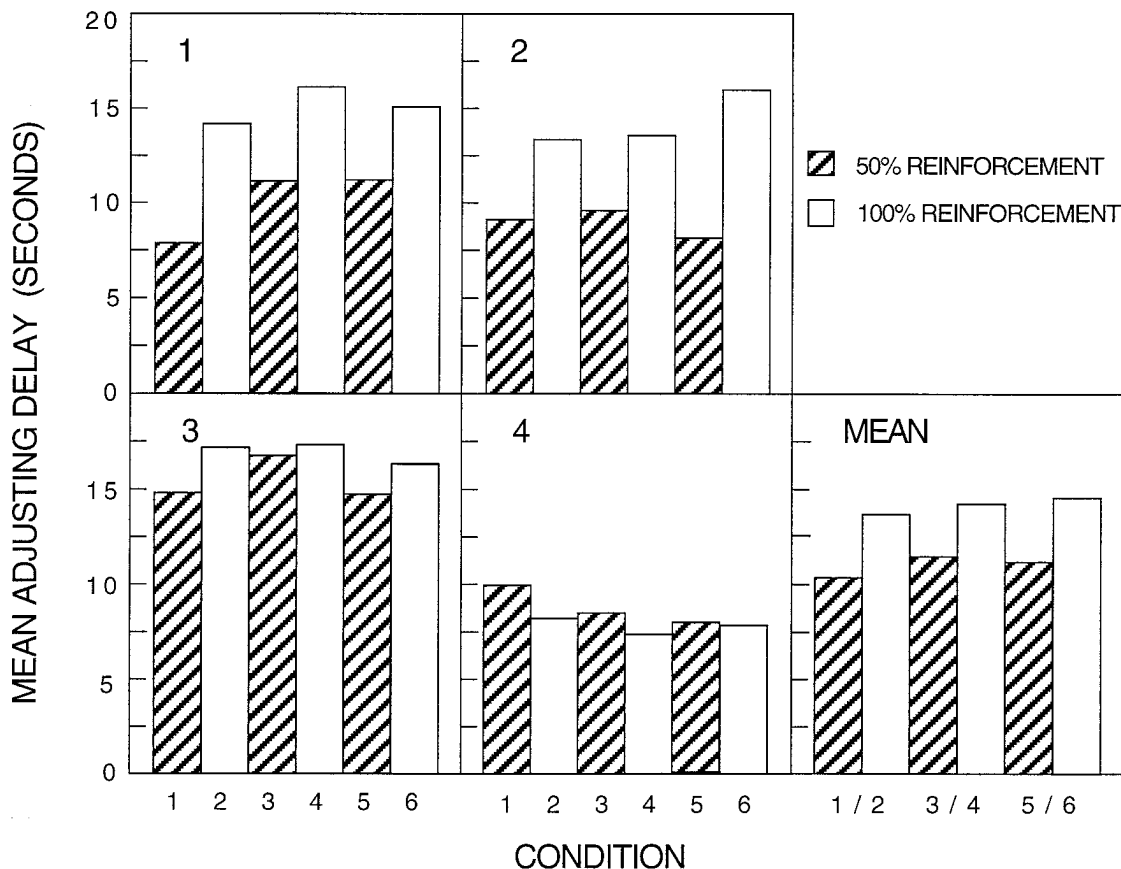


Fig. 2. For each subject in Part A, mean adjusting delays (indifference points) are shown for each condition.

choice response might account for some of the differences between the 100% and 50% alternatives. In Parts A and B, a choice of the 100% alternative had always been followed by the same stimulus (green houselights), whereas a choice of the 50% alternative had been followed by either green or white houselights. In Part C, the stimuli following a choice of the standard key were the same (half green and half orange) for both the 100% and 50% alternatives.

RESULTS

All analyses were based on the mean adjusting delays from the six blocks that satisfied the stability criteria by each subject in each condition. The number of sessions needed to meet these criteria ranged from 14 to 32 in the different conditions (median =

16 sessions). An alpha level of .05 was used for all statistical tests.

Figure 2 shows the mean adjusting delays from the six conditions in Part A, in which the standard delay was 10 s on half of the trials and 30 s on the rest. In the adjusting-delay procedure, smaller adjusting delays indicate greater preference for the standard alternative. The group means in Figure 2 therefore suggest that there was greater preference for the 50% standard alternative than the 100% alternative, because the adjusting delays averaged 10.7 s with the 50% alternative and 13.4 s with the 100% alternative. However, a repeated measures analysis of variance (ANOVA) found no significant effect of reinforcement probability, $F(1, 3) = 3.45$, no significant effect of replication, $F(1, 3) = 0.64$, and no significant interaction, $F(2, 6) = 0.43$. The absence of statistical significance

was a result of the large individual differences. Subjects 1 and 2 showed a clear effect of reinforcement probability that was repeated for all three replications. For these 2 pigeons, the mean adjusting delays averaged about 15 s with the 100% alternative and about 10 s with the 50% alternative, a difference that indicates a substantially greater preference for the 50% alternative. In contrast, Subjects 3 and 4 showed little or no consistent effect of reinforcement probability. These individual differences are similar to those found in previous studies (Belke & Spetch, 1994; Dunn & Spetch, 1990; Spetch et al., 1990).

Figure 3 shows the results from all 7 subjects that participated in Part B, in which the standard delay was always 20 s but the reinforcement probability varied from 20% to 100%. A repeated measures ANOVA conducted with the data from these 10 conditions showed a significant effect of condition, $F(9, 54) = 7.86, p < .001$. Much of this significant effect was due to the much longer adjusting delays in the 50% green conditions ($M = 32.7$ s) than in all other conditions ($M = 18.2$ s). These longer adjusting delays in the 50% green conditions were predicted by the hyperbolic decay model, because the green houselights were on for about twice as long per food delivery in these conditions. A planned comparison found a significant difference between the 50% green conditions and the other nine conditions, $F(1, 54) = 60.30, p < .001$.

Excluding the 50% green conditions, the group means suggest a slightly greater preference for the standard alternative when the reinforcement percentage was less than 100% (mean adjusting delay = 17.2 s) than when it was 100% (mean adjusting delay = 20.3 s). A planned comparison found a statistically significant difference between the three conditions with 100% reinforcement and the six conditions with either 20%, 50%, or 80% reinforcement, $F(1, 54) = 6.03, p < .05$. However, as in Part A, the difference between the 100% conditions and other conditions was only shown by some subjects. As can be seen in Figure 3, Subjects 2, 6, and 7 showed substantially greater preference for the partial reinforcement alternatives than for the 100% reinforcement alternative, whereas the other

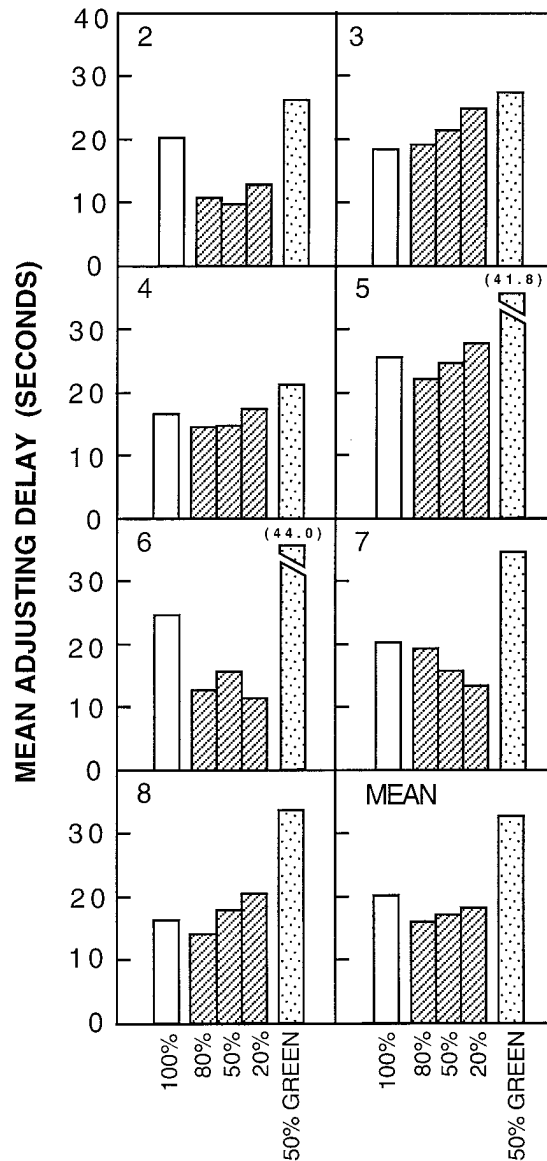


Fig. 3. For each subject in Part B, mean adjusting delays (indifference points) are shown for the five different types of conditions. The data are averaged across replications for conditions that occurred more than once.

4 subjects showed no consistent effect of this type.

Figure 4 shows the results from Part C, in which either green or orange houselights were present during the 20-s delays for the standard alternative. Recall that in the 50% reinforcement conditions, the houselight color was green on standard trials ending with reinforcement and orange on trials ending

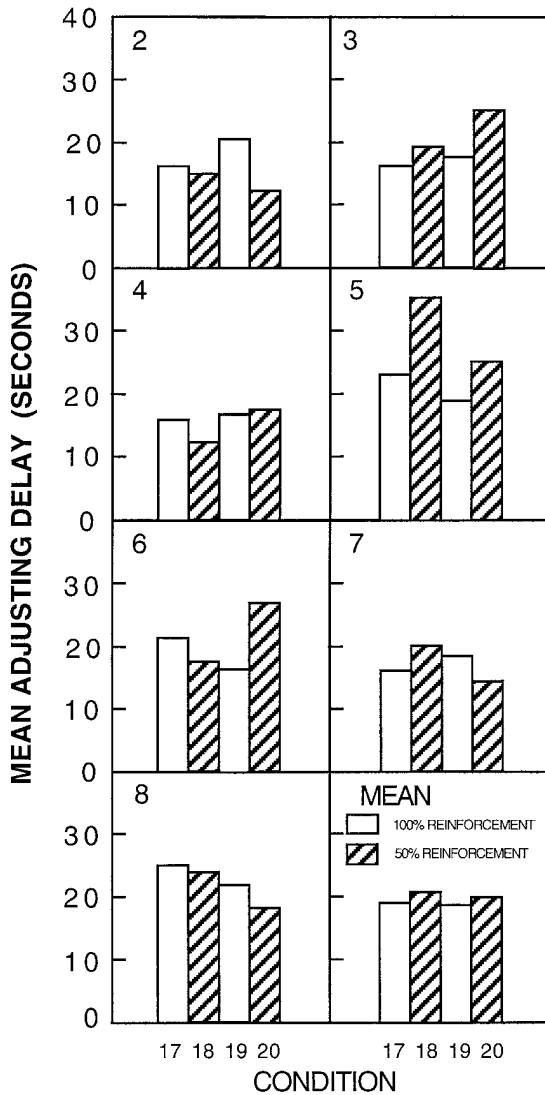


Fig. 4. For each subject in Part C, mean adjusting delays (indifference points) are shown for each condition.

without reinforcement. In the 100% reinforcement conditions, the green and orange houselights were each presented on a random half of the standard trials. The mean adjusting delay was 20.3 s in the 50% conditions and 18.9 s in the 100% conditions, so in contrast to Part B, the group as a whole did not show a greater preference for the 50% alternative under these conditions.

Next, separate analyses were conducted using only the data from the 3 pigeons that had shown substantial preference for the partial-reinforcement alternatives in Part B (Subjects

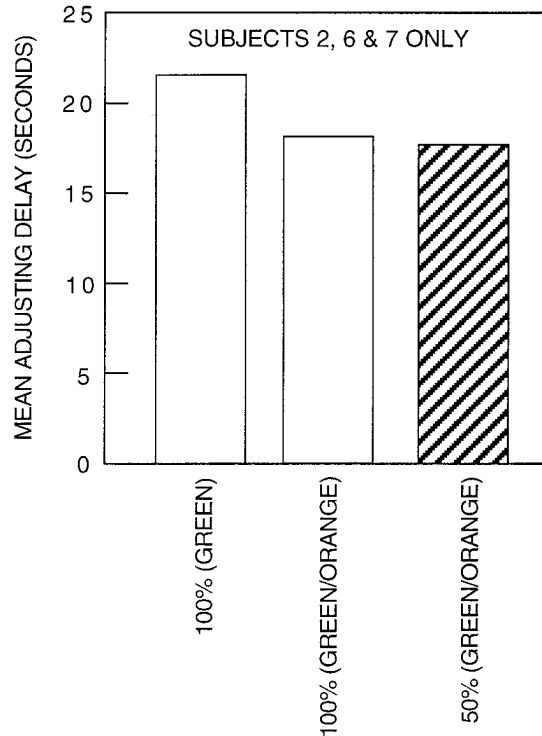


Fig. 5. For the 3 subjects that exhibited the strongest preference for partial reinforcement in Part B, mean adjusting delays (indifference points) are shown for the 100% reinforcement conditions of Part B and the 100% and 50% reinforcement conditions of Part C. The data are averaged across replications.

2, 6, and 7). Of course, any analysis based on the data from a selected subset of subjects must be viewed with caution, but in this case it seems worthwhile to focus on those subjects that had previously exhibited the preference for partial reinforcement. Figure 5 plots the mean results from these 3 pigeons for the 100% conditions of Part B (which had only green houselights for the standard alternative) and for the conditions of Part C (which included a mixture of orange and green houselights for the standard alternative). The mean adjusting delays were slightly smaller in both the 100% and 50% conditions of Part C than in the 100% conditions of Part B. An ANOVA performed on the data from these 3 subjects revealed no significant effect of condition, $F(6, 12) = 1.11$. However, a planned comparison found significantly larger indifference points in the three 100% conditions of Part B than in the four conditions of Part

C, $F(1, 12) = 5.17, p < .05$. This result therefore provides modest evidence that these 3 subjects had a stronger preference for the standard alternative when its houselight colors were variable (Part C) than when they were always green (Part B). Figure 4 shows that among these 3 subjects, only Subject 2 showed any sign of a consistent difference between the 50% and 100% conditions of Part C. In short, when variability in the houselight colors was equated, most of the differences between the 50% and 100% conditions disappeared.

DISCUSSION

The present experiment, which used an adjusting-delay procedure to measure preference, has provided several pieces of information about the counterintuitive preference for partial reinforcement over 100% reinforcement that has been reported in several previous studies. First, this effect was not found for all subjects. Varying the reinforcement percentage between 100% and 20% had little effect on the indifference points for about half the pigeons in this experiment. The hyperbolic decay model predicts this insensitivity to reinforcement percentage, because the time spent in the presence of the conditioned reinforcers (the red and green keylights and houselights) per food delivery remained fairly constant across conditions. What the hyperbolic decay model does not predict, however, is the preference for partial reinforcement over 100% reinforcement exhibited by the other half of the subjects.

Previous studies had also found this type of intersubject variability, but did not always rule out the possibility of color or position biases as the source of these individual differences (Dunn & Spetch, 1990; Spetch et al., 1990, 1994). The present experiment controlled these factors by keeping the houselight colors, keylight colors, and keylight positions constant across conditions, yet some subjects still showed a preference for partial reinforcement over 100% reinforcement.

Second, this experiment demonstrated the preference for partial reinforcement (by some subjects) with both variable delays (Part A) and fixed delays (Part B) to reinforcement. By measuring indifference points, the adjusting-delay procedure provided a way to

estimate the magnitude of the changes in preference. (Recall that smaller indifference points indicate a stronger preference for the standard alternative.) With the variable delays in Part A, indifference points for Subjects 1 and 2 averaged about 15 s with 100% reinforcement and about 10 s with 50% reinforcement. With the fixed delays in Part B, indifference points for Subjects 2, 6, and 7 averaged about 22 s with 100% reinforcement and about 13 s in the conditions with 20%, 50%, or 80% reinforcement. These indifference points showed that for some subjects, there was a substantial increase in preference as the reinforcement probability decreased from 100% to a lower percentage.

Third, for those subjects that did exhibit a preference for partial reinforcement in Part B (Subjects 2, 6, and 7), the indifference points did not change systematically as the reinforcement percentage was varied from 20% to 80%. This finding is difficult to interpret, but it could indicate that the preference for partial reinforcement was dependent on some degree of stimulus variability, but that the specific percentage of reinforced trials (and of the two houselight colors) was not critical.

The results from Part C provided more evidence that the preference for partial reinforcement might be due, at least in part, to variability in the delay stimuli in the conditions with partial reinforcement. In Part C, both the 100% and 50% reinforcement conditions had two different houselight colors (green or orange) during the delays for the standard alternative. With the houselight colors equally variable in all conditions, there were no systematic differences between the 50% and 100% conditions, except perhaps for Subject 2.

Results from this and previous studies on uncertain reinforcement are similar in some ways to the research on observing responses (Wyckoff, 1952). An observing response is an operant response that produces a switch from an unsignaled condition to a signaled condition. In the absence of an observing response, the subject is presented with a single stimulus regardless of whether or not reinforcement is available. If the subject makes the observing response, one stimulus (S+) is presented if reinforcement is currently available, and another stimulus (S-) is presented

if it is not. Many studies have shown that animals will regularly perform such observing responses, and that the S+ functions as a conditioned reinforcer (see Dinsmoor, 1983, and Fantino, 1977, for reviews). One difference from the present research, however, is that in studies of observing responses, the S- appears to have aversive properties (e.g., Blanchard, 1975; Dinsmoor, 1983; Mulvaney, Dinsmoor, Jwaideh, & Hughes, 1974). In contrast, the present results provided no evidence that the S- (the white houselights presented on trials without reinforcement) was aversive. In Part B, changing the proportion of standard trials with white houselights (and no food) from 20% to 80% had no systematic effect on the indifference points. The reasons for this result are not clear, but it is consistent with Equation 1, which affords no role to the S- in determining the value (V) of the uncertain alternative. Despite this difference, the results of this study and those on observing are similar in that they both appear to validate the concept of conditioned reinforcement, and they both question the usefulness of other theoretical accounts, such as those based on "information" or "uncertainty reduction."

In previous research on choice with certain and uncertain reinforcement, some findings have been robust and reliable, occurring consistently across subjects and experiments. Among these findings are the large differences between signaled and unsignaled conditions (Dunn & Spetch, 1990; Spetch et al., 1990), the effects of conditioned reinforcers (Mazur, 1995; Mazur & Romano, 1992), and the relative insensitivity to changes in reinforcement probabilities (Mazur, 1985, 1991). In contrast, the paradoxical preference for partial reinforcement over 100% reinforcement appears to be an unreliable and fragile phenomenon. First, the effect is found only in signaled conditions, in which different stimuli are presented on reinforcement trials and nonreinforcement trials. Second, the effect has usually been found in only a fraction of the pigeons. Third, for those pigeons that exhibit the effect, inserting a small delay between a choice response and the onset of the discriminative stimuli eliminates the effect (Belke & Spetch, 1994). Fourth, Part C of the present experiment showed that the effect can be largely eliminated by equating stimulus variability in 50% and 100% reinforcement

conditions. These findings suggest that the apparent preference for partial reinforcement depends critically on the precise arrangement of stimuli during the delay between a choice response and reinforcement. The effect, when it occurs, may be the result of idiosyncratic preferences for particular colors or for variability in the delay interval stimuli.

REFERENCES

- Belke, T. W., & Spetch, M. L. (1994). Choice between reliable and unreliable reinforcement alternatives revisited: Preference for unreliable reinforcement. *Journal of the Experimental Analysis of Behavior*, *62*, 353-366.
- Blanchard, R. (1975). The effect of S- on observing behavior. *Learning and Motivation*, *6*, 1-10.
- Dinsmoor, J. A. (1983). Observing and conditioned reinforcement. *Behavioral and Brain Sciences*, *6*, 693-728.
- Dunn, R., & Spetch, M. L. (1990). Choice with uncertain outcomes: Conditioned reinforcement effects. *Journal of the Experimental Analysis of Behavior*, *53*, 201-218.
- Fantino, E. (1969). Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, *12*, 723-730.
- Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313-339). Englewood Cliffs, NJ: Prentice Hall.
- Fantino, E., Dunn, R., & Meck, W. (1979). Percentage reinforcement and choice. *Journal of the Experimental Analysis of Behavior*, *32*, 335-340.
- Kendall, S. B. (1974). Preference for intermittent reinforcement. *Journal of the Experimental Analysis of Behavior*, *21*, 463-473.
- Kendall, S. B. (1985). A further study of choice and percentage reinforcement. *Behavioural Processes*, *10*, 399-413.
- Mazur, J. E. (1984). Tests of an equivalence rule for fixed and variable reinforcer delays. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*, 426-436.
- Mazur, J. E. (1985). Probability and delay of reinforcement as factors in discrete-trial choice. *Journal of the Experimental Analysis of Behavior*, *43*, 341-351.
- Mazur, J. E. (1986). Fixed and variable ratios and delays: Further tests of an equivalence rule. *Journal of Experimental Psychology: Animal Behavior Processes*, *12*, 116-124.
- Mazur, J. E. (1989). Theories of probabilistic reinforcement. *Journal of the Experimental Analysis of Behavior*, *51*, 87-99.
- Mazur, J. E. (1991). Choice with probabilistic reinforcement: Effects of delay and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior*, *55*, 63-77.
- Mazur, J. E. (1995). Conditioned reinforcement and choice with delayed and uncertain primary reinforcers. *Journal of the Experimental Analysis of Behavior*, *63*, 139-150.
- Mazur, J. E., & Romano, A. (1992). Choice with delayed and probabilistic reinforcers: Effects of variability,

- time between trials, and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior*, 58, 513-525.
- Mulvaney, D. E., Dinsmoor, J. A., Jwaideh, A. R., & Hughes, L. H. (1974). Punishment of observing by the negative discriminative stimulus. *Journal of the Experimental Analysis of Behavior*, 21, 37-44.
- Rachlin, H., Logue, A. W., Gibbon, J., & Frankel, M. (1986). Cognition and behavior in studies of choice. *Psychological Review*, 93, 33-45.
- Spetch, M. L., Belke, T. W., Barnet, R. C., Dunn, R., & Pierce, W. D. (1990). Suboptimal choice in a percentage-reinforcement procedure: Effects of signal condition and terminal-link length. *Journal of the Experimental Analysis of Behavior*, 53, 219-234.
- Spetch, M. L., Mondloch, M. V., Belke, T. W., & Dunn, R. (1994). Determinants of pigeons' choice between certain and probabilistic outcomes. *Animal Learning & Behavior*, 22, 239-251.
- Wyckoff, L. B., Jr. (1952). The role of observing responses in discrimination learning. *Psychological Review*, 59, 431-442.

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