EFFECTS OF INTERTRIAL REINFORCERS ON SELF-CONTROL CHOICE

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In three experiments, pigeons chose between a small amount of food delivered after a short delay and a larger amount delivered after a longer delay. A discrete-trial adjusting-delay procedure was used to estimate indifference points—pairs of delay-amount combinations that were chosen about equally often. In Experiment 1, when additional reinforcers were available during intertrial intervals on a variable-interval schedule, preference for the smaller, more immediate reinforcer increased. Experiment 2 found that this shift in preference occurred partly because the variable-interval schedule started sooner after the smaller, more immediate reinforcer, but there was still a small shift in preference when the durations and temporal locations of the variable-interval schedules were identical for both alternatives. Experiment 3 found greater increases in preference for the smaller, more immediate reinforcer with a variable-interval 15-s schedule than with a variable-interval 90-s schedule. The results were generally consistent with a model that states that the impact of any event that follows a choice response declines according to a hyperbolic function with increasing time since the moment of choice.

Key words: self-control, reinforcer delay, reinforcer amount, intertrial reinforcers, key peck, pigeons

In one type of self-control choice situation, an individual must choose between a small, fairly immediate reinforcer and a larger, more delayed reinforcer. Which choice the individual makes depends on many factors, such as exactly how large the two reinforcers are, how long the two delays are, and how the individual's behavior is affected by increasing delay. To predict which choice will be made, it is important to know the relation between a reinforcer's delay and its *value*—its ability to sustain instrumental responding. Several experiments with pigeons (e.g., Davison & Smith, 1986; Grossbard & Mazur, 1986; Mazur, 1987; Rodriguez & Logue, 1988) have found that the relation between a reinforcer's delay and its value is well described by the following hyperbolic equation:

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

where V is the value of a reinforcer delayed

D seconds, A is monotonically related to the amount of reinforcement, and K is a free parameter. Extensions of this hyperbolic equation have been successfully applied to other choice situations, such as choices between fixed and variable delays (Mazur, 1984) and choices between single and multiple delayed reinforcers (Mazur, 1986).

Much of the evidence for this hyperbolic relation has been based on the analysis of *indifference points*—pairs of alternatives that a subject chooses about equally often. For example, suppose that by pecking one key a pigeon can obtain 2 s of access to grain after a 10-s delay. If a peck on a second key delivers 6 s of access to grain after a 10-s delay, it should be clear (both from Equation 1 and from common sense) that the 6 s of access to grain has a higher value and will be chosen. If, however, the delay for the 6 s of grain is now systematically increased, the value of this alternative will gradually decrease, and eventually a point will be reached (the indifference point) at which the pigeon chooses the two alternatives equally often. (In Mazur's 1987 experiment, the indifference point in this particular case was reached when the delay for the larger reinforcer, averaged across 4 subjects, was about 26 s.) If the delay for the large reinforcer is increased further, the subject will begin to exhibit what has been called "impulsive behavior," choosing the smaller, more immediate reinforcer.

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To estimate indifference points, Mazur (1987) used a discrete-trial adjusting-delay procedure. In this procedure, the delay for one alternative, the *standard alternative*, was constant throughout a condition. The delay for the other alternative, the *adjusting alternative*, was changed many times a session. Each choice of the standard alternative always delivered 2 s of access to grain, and the adjusting alternative always delivered 6 s of access. Once an indifference point was estimated, the next condition began, with a different delay for the standard alternative. Across conditions, the delay for the standard alternative was varied from 0 s to 20 s, and for each standard delay, the duration of the adjusting delay at the indifference point was measured.

Let us assume that at each indifference point, $V_a = V_s$, where the subscripts refer to the adjusting and standard alternatives, respectively. Given this assumption, Equation 1 predicts that if each adjusting delay is plotted as a function of each corresponding standard delay, the results should follow a linear function with a slope greater than 1 and a y intercept greater than 0. For each of the 4 subjects, Mazur (1987) found results that were consistent with the following prediction: The indifference points approximated linear functions, with slopes averaging 2.4 and y intercepts averaging 2.6 s. Mazur showed that these results were inconsistent with other common delay-of-reinforcement functions, including an exponential equation of the form $V = A \exp(-KD)$ and a reciprocal equation of the form $V = A/(KD)$.

Although Equation 1 has been successfully applied to several different choice situations, Mazur and Kralik (1990) pointed out that this equation is too simple to apply to more complex cases. In their experiment, pigeons obtained reinforcers on fixed-ratio (FR) schedules, and relatively forceful pecks were required to operate the response key. Mazur and Kralik proposed that whereas food has a positive value, forceful key pecking has a negative value (in other words, it is somewhat aversive). There is no easy way for Equation 1 to accommodate events of both positive and negative value (or, for that matter, two events of different positive values). To deal with such cases, Mazur and Kralik presented what can be considered a more general version of the hyperbolic-decay model.

The model proposed by Mazur and Kralik

(1990) assumes that V , the value of a given choice alternative, is influenced by all of the events that follow a choice response. The model states that every event, whether it is an activity (e.g., key pecking) or a stimulus (e.g., food, shock), can be assigned a number, Q , that represents the quality of that event (its reinforcing or punishing properties). Q will be positive for reinforcing events and negative for punishing events. Naturally, creatures will tend to choose alternatives that include events with high positive values of Q as opposed to low or negative values. However, two other factors also influence the choice response: (a) the duration of each event, and (b) each event's temporal proximity to the moment of choice. Let t represent the amount of time that has elapsed since the choice response. The model assumes that the contribution of the event occurring at time t to V , the value of the choice alternative, is equal to $Q_t W_t$, where Q_t is the quality of the event occurring at time t , and W_t is a weighting factor that decreases as t increases, as follows:

$$W_t = \frac{1}{1 + Kt}. \quad (2)$$

Like Equation 1, Equation 2 assumes that the impact of an event on V decreases hyperbolically as delay increases, but the latter equation describes the weighting of an instantaneous event, not one extended in time. The product $Q_t W_t$ is the instantaneous contribution of the event occurring at time t to V , the value of the choice alternative. To calculate the total value of an event extended in time, we can integrate over the total duration of that event:

$$V_x = \int_{t_1}^{t_2} Q_t W_t dt = \int_{t_1}^{t_2} \left(\frac{Q_t}{1 + Kt} \right) dt, \quad (3)$$

where V_x is the total value of an event, x , that begins at time t_1 and ends at time t_2 . To calculate the total value, V , of a choice alternative that is composed of several different events, we can integrate over the total time period from the moment of choice, t_0 , to the end of the trial, t_{end} (assuming for now that events beyond the end of the trial do not affect the choice response):

$$V = \int_{t_0}^{t_{\text{end}}} \left(\frac{Q_t}{1 + Kt} \right) dt. \quad (4)$$

Finally, the model assumes that in a choice

situation, an organism will choose whichever alternative has the highest value.

To see how this model might be applied to a simple choice situation, suppose that if a pigeon pecks the left key, there is a 10-s delay, then food is presented for 5 s, and then an aversive stimulus (a loud noise) is presented for 10 s. Assume that food has positive quality, delay has zero quality, and noise has negative quality. If the pigeon pecks the right key, the resulting sequence is 10 s of noise, then 5 s of food, then 10 s of delay. The hyperbolic-decay model predicts that the pigeon will show a preference for the left alternative, and Figure 1 illustrates why. Although the events and their durations are the same for the two alternatives, the noise (with its negative quality) is weighted more heavily for the right alternative because it occurs closer to the moment of choice. Conversely, if the noise happened to have a slightly positive quality, the pigeon would show a preference for the right alternative, again because the noise is closer to the moment of choice on the right key.

In summary, the hyperbolic-decay model described by Equations 2 through 4 retains the idea that the impact of an event on choice responding decreases as the event's delay increases. However, this model is more versatile than Equation 1 because it can be applied to alternatives that include multiple events of different types (qualities), durations, and temporal locations. It will be useful to apply this more general model to the analysis of the present series of experiments, in which several different types of events occurred after a choice response.

The present experiments were conducted to determine how the presence of reinforcers during intertrial intervals (ITIs) would affect self-control choices. Other research has examined how extraneous stimuli can affect self-control choices, but these stimuli have generally been presented during the delays before reinforcement, not between trials. For example, Grosch and Neuringer (1981) conducted a set of studies in which pigeons could receive a less preferred reinforcer immediately or a more preferred reinforcer after a 15-s delay. They found that the pigeons were more likely to wait for the preferred reinforcer if both reinforcers were visible but out of reach during the delay. In another experiment, they observed more choices of the preferred reinforcer when food pellets were available on an FR 20 schedule during

Fig. 1. An illustration of how the hyperbolic-decay model gives different weights to events depending on their temporal distance from the moment of choice.

the delay. Similar studies have been conducted with children by Mischel and his colleagues (e.g., Mischel & Baker, 1975; Mischel & Ebbsen, 1970; Mischel, Ebbsen, & Zeiss, 1972). In contrast to these studies, the present experiments arranged no events during the delays before reinforcement, but reinforcers were available between trials on a variable-interval (VI) schedule. Experiment 1 examined how the presence of the VI schedule affected preference, and the delay for the small reinforcer was varied across conditions. Experiment 2 explored three different possible reasons why the intertrial VI schedule might affect choice. Experiment 3 sought to determine whether the magnitude of the effect was determined by the rate of reinforcement delivered by the VI schedule.

EXPERIMENT 1

In this experiment, pigeons chose between 2.5 s of access to grain after a fixed delay and

Fig. 2. Representative predictions of the hyperbolic-decay model for indifference points in a choice between a 2.5-s reinforcer and a 6-s reinforcer. When an intertrial VI 15-s schedule is added, the model predicts that the delays for the larger reinforcer will decrease, thus demonstrating an increase in preference for the smaller reinforcer.

6 s of access after a delay that was adjusted to find the indifference point. In different conditions, the delay for the small reinforcer was varied from 2 to 10 s. In some conditions, a VI 15-s schedule was in effect during the ITIs, and in other conditions there was no VI schedule during the ITIs. According to the hyperbolic-decay model, the presence of the VI schedule should cause a decrease in the indifference points. That is, subjects should show a decreased preference for the larger, more delayed reinforcer.

Figure 2 presents the sort of predictions made by the hyperbolic-decay model. To make the predictions for the conditions with no VI schedule, it was arbitrarily assumed that $K = 1$, $Q_d = 0$, $Q_i = 0$, and $Q_f = 100$, where the subscripts refer to the delay, the ITI, and the food, respectively. Although the number of free parameters may seem large, the qualitative

predictions of the model do not depend heavily on the exact parameter values chosen. In fact, if K is held constant, the predictions of Equation 4 are identical with any other numerical values as long as $Q_d = Q_i$ and Q_f is larger than the other two. Therefore, the predictions for no VI schedule depend only on the value of K . As already mentioned, the model predicts that the indifference curve will be linear, with a slope greater than 1 and a y intercept greater than 0.

To make the predictions for the conditions with the intertrial VI 15-s schedule, Q_i was set equal to 11. This value was used because reinforcers were randomly distributed throughout the ITIs, and with 2-s reinforcers occurring roughly once every 15 s, the food was actually present during about 11% of the ITI time (so Q_i was set at 11% of Q_f). However, the predictions for the conditions with an intertrial VI are qualitatively similar as long as Q_i is greater than Q_d and less than Q_f . As Figure 2 shows, the model predicts that the indifference points will decrease when the intertrial VI schedule is added, and that the decrease will be more pronounced with longer delays for the small reinforcer. With the intertrial VI, the indifference function is not as steep, and the function is not quite linear.

METHOD

Subjects

The subjects were 4 White Carneau pigeons maintained at approximately 80% of their free-feeding weights. All had previous experience with a variety of experimental procedures, and required no pretraining for this experiment.

Apparatus

The experimental chamber was 30 cm long, 30 cm wide, and 32 cm high. Three response keys, each 1.8 cm in diameter, were mounted in the front wall of the chamber, 23 cm above the floor. A force of approximately 0.1 N was required to operate each key, and each 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 blue) were mounted above the wire-mesh ceil-

Table 1

Order of conditions and mean adjusting delays for each subject in Experiment 1. All durations are in seconds.

Standard delay	VI present?	Order of conditions		Mean adjusting delay			
		Subjects 1 & 2	Subjects 3 & 4	Subject 1	Subject 2	Subject 3	Subject 4
6	yes	1	2	3.94	16.94	11.47	16.75
6	no	2	1	14.44	27.38	19.00	26.30
6	yes	3	4	6.81	14.72	10.47	16.53
6	no	4	3	14.11	23.51	11.50	33.02
10	yes	5	6	8.67	17.17	17.97	27.11
10	no	6	5	21.36	38.67	17.22	39.33
2	no	7	8	7.33	4.49	6.36	14.20
2	yes	8	7	3.83	4.78	7.64	11.11
10	no	9	10	16.57	36.03	27.75	38.35
10	yes	10	9	8.06	21.64	20.08	28.64

ing of the chamber. The 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

The experiment consisted of 10 conditions, each of which remained in effect for 12 or more sessions. In five of the conditions, a VI 15-s schedule was in effect during each ITI, and in the other five conditions it was not. The order of conditions is shown in Table 1. Notice that the presence or absence of the VI schedule was counterbalanced, with Subjects 1 and 2 receiving one order and Subjects 3 and 4 another order.

The procedure for conditions without the ITI will be described first. All sessions lasted for 48 trials or for 60 min, whichever came first. Each block of four consecutive trials consisted of two forced trials followed by two choice trials. 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. On choice trials, 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.

Figure 3 illustrates the consequences of choosing either the green or the red key. A single peck on the green key extinguished both keylights and led to a standard delay, during which the green houselights were lit. In different conditions, the standard delay was either 2 s, 6 s, or 10 s. At the end of the standard delay, the green houselights were extinguished and grain was presented for 2.5 s. During this and all presentations of grain, the only light in the chamber was the white light illuminating the grain hopper. After this reinforcement period, the white houselights were lit and an ITI began. The duration of the ITI was set so that the total time from the choice response

Fig. 3. A diagram (not drawn to scale) of the consequences of pecking either the green key (G) or the red key (R) in the conditions of Experiment 1 with no intertrial VI. HL = houselight.

on the green key to the start of the next trial was 66 s.

If the red key was pecked during the choice period, both keylights were extinguished and an adjusting delay began, during which the red houselights were lit. (The method for determining the duration of the adjusting delay is described below.) At the end of the adjusting delay, the red houselights were extinguished and grain was presented for 6 s. After this reinforcement period, an ITI with white houselights began, and as with the standard alternative, the ITI duration was set so that the total time from the choice response to the start of the next trial was 66 s.

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.

In this experiment, the adjusting delay could range from a minimum of 0 s to a maximum of 40 s, and its duration was determined as follows. At the start of each 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. 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.

For the five conditions with a VI schedule present during the ITIs, the procedure was the same as already described, except that during all ITIs, the center key was blue (rather than dark), and pecks on the center key were reinforced on a VI 15-s schedule. During each second of every ITI, there was a .0667 probability that a reinforcer would be stored, and then the next peck on the blue key would deliver the reinforcer—a 2-s grain presentation. At the end of each ITI, the center key color changed from blue to white for the start of the

next trial. If a reinforcer was stored but not delivered during one ITI, the first response on the blue key during the next ITI produced the reinforcer.

Condition 1 lasted for a minimum of 20 sessions, and all other conditions lasted for a minimum of 12 sessions. A condition was then terminated for each subject individually when several stability criteria were met. To assess stability, each session was divided into two 24-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 three criteria were met, using the data from all subsequent 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). In one condition, the adjusting delays for Subject 4 showed atypically large fluctuations when these criteria were first met, so the condition was continued for an additional 10 sessions and then terminated when the criteria were again met.

RESULTS AND DISCUSSION

For every condition, the mean adjusting delay from the six half-session blocks that satisfied the stability criteria was used as an estimate of the indifference point. Table 1 shows these durations for each subject. The results are also presented in Figure 4, in which the indifference points are averaged across replications for those conditions that were repeated. The results from the conditions with no intertrial VI were generally consistent with the predictions of the hyperbolic-decay model, which predicts slopes greater than 1 and y intercepts greater than 0. Regression lines were calculated for the results from the no VI conditions. The slopes of these lines were substantially greater than 1 for all subjects (ranging from 1.46 for Subject 1 to 4.11 for Subject 2, with a mean slope of 2.67). For 3 of 4 subjects, the y intercepts were greater than 0 (ranging from -2.2 for Subject 2 to 9.1 for Subject 4, with a mean y intercept of 3.6 s).

These results are consistent with those obtained in previous experiments that used very similar procedures (Mazur, 1987; Rodriguez & Logue, 1988).

In the five conditions with the intertrial VI schedule, all subjects responded consistently and received many reinforcers from the VI schedule. For the 4 subjects, response rates on the blue key averaged approximately 90, 64, 74, and 72 responses per minute. All 4 subjects obtained an average of one reinforcer from the VI schedule every 16 s. On average, subjects received 134 reinforcers from the VI schedule per session.

In general, the presence of the intertrial VI schedule caused a decrease in the indifference points (Figure 4), especially when the delay for the small reinforcer was larger. With the 2-s delay for the small reinforcer, only 2 of the 4 subjects showed a reduction in the indifference points. However, all 4 subjects had shorter indifference points with the 6-s and 10-s delays. With a 6-s delay for the small reinforcer, the mean indifference point was 12.2 s with the VI schedule, and 21.1 s without it. With a 10-s delay for the small reinforcer, the mean indifference point was 18.7 s with the VI and 29.4 s without it. A two-way repeated-measures analysis of variance found a significant effect of the presence of the intertrial VI, $F(1, 3) = 35.75$, $p < .01$, and a significant effect of the duration of the delay for the small reinforcer, $F(2, 6) = 21.53$, $p < .01$. The interaction of VI presence and delay duration was also statistically significant, $F(2, 6) = 14.18$, $p < .01$.

A comparison of Figures 2 and 4 shows that the results from this experiment were generally consistent with the predictions of the hyperbolic-decay model. The effect of the intertrial VI schedule was to decrease the indifference points, and this effect was larger with longer delays for the small reinforcer. With the intertrial VI, the model predicts that the indifference function will be slightly curvilinear (solid curve in Figure 2), but the predicted departure from linearity is slight, and the results in Figure 4 showed no clear evidence for such curvilinearity.

Although these results are consistent with the hyperbolic-decay model, they provide little or no information about *why* the presence of the intertrial VI schedule caused a decrease in the indifference points. This decrease in the

Fig. 4. For each of the 4 subjects, the mean adjusting delays at the indifference point are shown for the different standard delays used in Experiment 1, for conditions with and without an intertrial VI schedule. For conditions that were repeated, the results were averaged across replications.

indifference points amounts to a decrease in preference for the adjusting alternative (or conversely, to an increase in preference for the standard alternative). This experiment does not tell us why the subjects chose to wait less time for the larger delayed reinforcer than they did in conditions without the VI schedule. Experiment 2 was designed to examine three possible explanations.

EXPERIMENT 2

The hyperbolic-decay model suggests at least two reasons why preference for the standard alternative increased when the intertrial VI schedule was present. First, because the adjusting delay was longer than the standard delay at the indifference point, the start of the VI schedule occurred closer to the moment of choice for the standard alternative. The model clearly predicts that, if all else is held constant, an event of positive quality will have a greater impact on choice if it occurs closer to the moment of choice. Second, the total duration of

the VI schedule was longer after standard trials than after adjusting trials, because the total time from the choice response until the start of the next trial was held constant at 66 s. A third possibility (one that does not follow as easily from the hyperbolic-decay model) is that when the VI schedule was present during the ITIs, the delays associated with the small and large alternatives became more aversive because they served as timeouts from positive reinforcement. Other studies have shown that periods of timeout from positive reinforcement are aversive and elicit avoidance responses (Ferster, 1958; Galbicka & Branch, 1983; Thomas, 1965). If the delays were aversive, the longer delay associated with the adjusting alternative would presumably be more aversive, and subjects might therefore show a shift in preference toward the standard alternative.

To test these different possibilities, the intertrial VI schedule was manipulated in several ways. In some conditions, both the duration of the VI schedule and its time of onset were equated for the standard and adjusting alternatives. In other conditions, its duration was equated but time of onset was not. In a third type of condition, neither was equated.

METHOD

Subjects and Apparatus

The 4 pigeons from Experiment 1 served in this experiment, and the same apparatus was used.

Procedure

Except as noted below, the details of the procedure, including the arrangement and durations of stimuli, the rules for changing the adjusting delay, and the criteria for terminating conditions were the same as in Experiment 1. The experiment consisted of 12 conditions that used four different procedures. These will be called the no VI, the delayed VI, the immediate VI, and the full VI procedures.

The first six conditions included repeated comparisons of the no VI and delayed VI procedures. The no VI procedure was identical to that of Experiment 1, except that the standard delay associated with the left green key was always 8 s. The adjusting delay could vary between 5 s and 50 s, and was adjusted according to the same rules as in Experiment 1. This procedure was used in Conditions 2, 4, and 6.

The delayed VI procedure was used in Conditions 1, 3, and 5. This procedure arranged an intertrial VI schedule in such a way that the time of onset and the total duration of the VI schedule were the same for both alternatives. As in Experiment 1, when the center key was blue, pecks on this key were reinforced on a VI 15-s schedule. After each trial with the adjusting alternative, the center key was blue and the VI schedule was in effect during the entire ITI. However, after trials with the standard alternative, the VI 15-s schedule was not in effect for the first part of the ITI. As illustrated in Figure 5, immediately after the standard reinforcer was delivered, the center key was dark and the VI schedule was not in effect. The VI schedule was delayed so that the time between the choice response and the onset of the VI schedule matched that of the adjusting alternative for that block of four trials.

For example, if the adjusting delay was currently 20 s in duration, the sequence on an adjusting trial would be as follows: a 20-s delay, 6-s access to grain, then 40 s with the center key blue and the VI schedule in effect (for a total of 66 s). All trials with the standard alternative during this block of four trials would have the following sequence: an 8-s delay, 2.5-s access to grain, 15.5 s with the center key dark, then 40 s with the center key blue and the VI schedule in effect (for a total of 66 s). Thus for both alternatives, the VI schedule began 26 s after the choice response and lasted for 40 s. The minimum possible adjusting delay was set at 5 s in this procedure (and in all conditions of this experiment) so that it would always be possible to match the durations of the VI schedules for the standard and adjusting alternatives.

The next five conditions involved repeated comparisons of the delayed VI procedure (Conditions 8 and 10) and the immediate VI procedure (Conditions 7, 9, and 11). The delayed VI procedure was the same as that described above. In the immediate VI procedure, the duration of the VI schedule was matched for the two alternatives, but its temporal location was not. As shown in Figure 5, the blue center key was illuminated immediately after reinforcement for both alternatives, and the VI 15-s schedule was in effect. For the adjusting alternative, the VI schedule was present throughout each ITI. For the standard alternative, the duration of the blue key and VI schedule was matched to that of the adjusting

Fig. 5. A diagram (not drawn to scale) of the consequences of pecking either the green key (G) or the red key (R) in the four different procedures used in Experiment 2. HL = houselight.

Fig. 6. For each subject, mean adjusting delays at the indifference point are shown for Conditions 7 through 11 of Experiment 2, which compared the immediate VI and delayed VI procedures.

alternative for the current block of four trials. This meant that after standard trials, the blue key and VI schedule were turned off before the end of the ITI, and there was a period in which the only stimuli present were the white houselights. As in the delayed VI procedure, the total time from a choice response to the start of the next trial was always 66 s.

The full VI procedure was used in Condition 12. The standard delay was 8 s, but in all other respects this condition was the same as the VI conditions of Experiment 1, with the VI 15-s schedule present throughout all ITIs (see Figure 5).

RESULTS AND DISCUSSION

For every condition, the mean adjusting delay from the six half-session blocks that satisfied the stability criteria was used as an estimate of the indifference point. Figure 6 presents the results from Conditions 7 through 11, which compared the immediate VI and delayed VI procedures. For each subject, the indifference points were shorter in the immediate VI conditions, thus demonstrating a stronger preference for the standard alternative when the VI schedule began immediately after the standard reinforcer was delivered (and closer to the moment of choice than for the adjusting alternative). The mean adjusting delay at the indifference point was 13.8 s in the immediate VI conditions and 19.5 s in the delayed VI conditions. A repeated-measures

Fig. 7. For each subject, mean adjusting delays at the indifference point are shown for Conditions 1 through 6 of Experiment 2, which compared the no VI and delayed VI procedures.

analysis of variance found a statistically significant difference among these five conditions, $F(4, 12) = 5.35$, $p < .05$. A planned comparison showed that the three immediate VI conditions had significantly shorter indifference points than the two delayed VI conditions, $F(1, 12) = 19.41$, $p < .01$.

Figure 7 presents the indifference points from Conditions 1 through 6, which compared the no VI and delayed VI procedures. In the delayed VI procedure, the VI schedules were equal in duration and temporal placement for the standard and adjusting alternatives, so the question was whether the effects of these VI schedules would cancel out, thus yielding indifference points that were similar to those of the no VI conditions. The results, however, showed slightly shorter indifference points in the delayed VI conditions. The differences between the two procedures were small in some cases, especially for Subject 3. Averaged across subjects, the mean adjusting delay was 20.1 s in the delayed VI conditions and 25.8 s in the no VI conditions. A repeated-measures ANOVA found a statistically significant effect of condition, $F(5, 15) = 3.59$, $p < .05$, and a planned comparison found a significant dif-

ference between the delayed VI and no VI conditions, $F(1, 15) = 7.33, p < .05$.

Figure 8 summarizes the results from the four different procedures used in this experiment, averaged across all replications. The results were similar for all 4 subjects. Preference for the adjusting alternative was greatest (i.e., indifference points were longest) when there was no intertrial VI schedule. The results from the delayed VI conditions showed that the mere presence of the VI schedules produced a reduction in preference for the adjusting alternative, even when the duration and temporal location of the VI schedule were the same for both the standard and adjusting alternatives. This finding will be examined in more detail in the General Discussion, but it may indicate that the delays before reinforcement became more aversive when they represented timeouts from the VI schedule that was present at other times.

Preference for the adjusting alternative decreased further in the immediate VI conditions, thus demonstrating that the temporal proximity of the VI schedule had an effect on preference in the manner predicted by the hyperbolic-decay model. Finally, the results from the full VI condition were similar to those from the immediate VI conditions. A paired-sample t test found no statistically significant difference between the full VI and immediate VI conditions, $t(3) = 0.27$. Shorter indifference points might be expected for the full VI condition, because the VI schedule was present for a longer time after the standard alternative. However, the hyperbolic-decay model actually predicts only a small difference between the immediate VI and full VI conditions, and the diagrams in Figure 5 help to explain why: The only difference between the two conditions was the absence of the VI schedule at the end of the ITI in the immediate VI condition. Because this portion of the ITI occurred farthest from the moment of choice, what happened in this period should have had less impact on the choice response. In fact, using the same parameter values used to generate the predictions shown in Figure 2, the hyperbolic-decay model predicted that the indifference points from these two conditions should differ by only about 1 s. Considering the variability in the data, the actual results shown in Figure 8 are in agreement with this prediction.

Fig. 8. For each subject, mean adjusting delays at the indifference point are shown for the four procedures used in Experiment 2. The results are averaged across replications where applicable.

In summary, the immediacy of the VI schedules had a large effect on the indifference points, whereas the total durations of the VI schedules had much less effect in these circumstances. These results were consistent with the predictions of the hyperbolic-decay model. The mere presence of the intertrial VI schedules caused a modest increase in preference for the smaller, more immediate reinforcer, even when the durations and temporal locations of the VI schedules were the same for the two alternatives.

EXPERIMENT 3

The hyperbolic-decay model suggests that self-control choices will be affected not merely by the presence or absence of an intertrial VI but also by the quality of the VI schedule. An intertrial VI schedule with a high rate of reinforcement should have a greater effect on choice than one with a lower rate of reinforcement. Experiment 3 tested this prediction.

Fig. 9. For each subject, mean adjusting delays at the indifference point are shown for the three procedures used in Experiment 3. The filled circles are the group means. The results are averaged across replications.

METHOD

Subjects and Apparatus

The 4 pigeons from Experiment 2 served in this experiment, and the same apparatus was used.

Procedure

Except as noted below, the details of the procedure, including the arrangement and durations of stimuli, the rules for changing the adjusting delay, and the criteria for terminating conditions, were the same as in Experiment 2. The experiment included five conditions, and the standard delay was always 8 s. Conditions 2 and 4 were identical in all respects to the no VI conditions of Experiment 2. Condition 5 was a full VI condition identical to that of Experiment 2. Because the last condition of Experiment 2 was also a full VI condition, the results from this condition were combined with those of Condition 5 in the data analysis. Conditions 1 and 3 were the same as the full VI conditions, except that a VI 90-s schedule was used in place of the VI 15-s schedule.

RESULTS AND DISCUSSION

The hyperbolic-decay model predicts that indifference points should be largest in the no VI conditions, slightly smaller in the VI 90-s conditions, and substantially smaller in the VI

15-s conditions. That is, because a VI 90-s schedule delivers only one sixth as many reinforcers as a VI 15-s schedule, its effect on the indifference points should be several times smaller. For every condition, the mean adjusting delay from the six half-session blocks that satisfied the stability criteria was used as an estimate of the indifference point. Figure 9 presents the indifference points for each subject and for the group, averaged across replications. There was substantial variability among subjects, but the group mean indifference point was 14.3 s with VI 15 s, 18.2 s with VI 90 s, and 19.8 s with no VI. A repeated-measures ANOVA found only a borderline effect of condition, $F(2, 6) = 4.84$, $p = .056$, on the group average. However, a planned comparison found a statistically significant difference between the VI 15-s condition and the other two conditions, $F(1, 6) = 8.86$, $p < .05$. A second planned comparison found no statistically significant difference between the VI 90-s and no VI conditions, $F(1, 6) = 0.80$. These results are in general agreement with the predictions, and they clearly show that the rate of intertrial reinforcers, not simply their presence or absence, is an important factor.

GENERAL DISCUSSION

The main conclusion from this series of experiments is that events occurring between trials can affect choice in a self-control situation. More specifically, when reinforcers were available during the ITI, the subjects showed greater "impulsiveness"; that is, greater preference for the smaller, more immediate reinforcer (as demonstrated by the decreased duration of the adjusting delay that preceded the larger reinforcer). Experiment 1 showed that the effect of the intertrial reinforcers were most pronounced when the delays to the standard and adjusting alternatives were long. Experiment 3 showed that a rich intertrial reinforcement schedule had more effect on self-control choices than did a leaner schedule.

Experiment 2 demonstrated that the shift in preference toward the smaller, more immediate reinforcer was largely due to the fact that onset of the VI schedule occurred earlier after a choice for this alternative. That is, because the durations of both the standard delay and the standard reinforcer were smaller than those for the adjusting alternative, the standard trial was over faster and the VI schedule resumed

more promptly. The fact that the VI schedule was also longer after a standard trial was less important, as demonstrated by the similarity of the results from the full VI and immediate VI conditions of Experiment 2.

These experiments examined the effects of intertrial reinforcers using a specific procedure (the adjusting-delay procedure); whether the results can be generalized to other choice procedures remains to be seen. However, Mazur (1988) showed that varying some of the arbitrary features of this procedure (i.e., the number of choice trials per block, the size of the increments in the adjusting delay, and trial duration) had no systematic effects on the indifference points obtained. In addition, the adjusting-delay procedure has been used in a variety of choice situations with both human and nonhuman subjects, and results from these studies seem to be compatible with results obtained with other choice procedures, such as concurrent or concurrent-chains schedules (e.g., King, Logue, & Gleiser, 1992; Mazur, 1984, 1986, 1987; Rodriguez & Logue, 1988; Tobin, Chelonis, & Logue, 1993).

In most respects, the present results agreed with the predictions of the hyperbolic-decay model developed by Mazur and Kralik (1990). This model is mathematically more complex than the delay equation used by Mazur (1987), but its advantages should be emphasized. First, although mathematically more difficult, the model is conceptually very simple: It states that value of an alternative is affected by all the events that follow a choice response, and the impact of each event depends on its quality, delay, and duration. Second, and more important, the model is flexible enough to deal with multiple events that vary in their qualities, delays, and durations. Mazur and Kralik pointed out that there is no obvious way to incorporate events of both positive and negative quality into Equation 1. For example, suppose the delay before food is filled with some aversive event (as illustrated in the bottom part of Figure 1). There is no simple way to handle this situation using Equation 1, but Equations 2 through 4 can easily be applied by assuming that the aversive event has negative quality and the food has positive quality. Transposing the order of positive and negative events (Figure 1, top) is equally easy for the more general hyperbolic-decay model to deal with.

Although most of the results from these

studies are quite consistent with the predictions of the hyperbolic-decay model, the finding of a difference between the no VI and delayed VI conditions of Experiment 2 poses more of a challenge for the model. Recall that in the delayed VI procedure, the standard and adjusting alternatives had VI schedules that were equal both in duration and in temporal remoteness from the choice response. The hyperbolic-decay model predicts that if two alternatives are already equal in value, adding identical events at identical locations to each should keep the alternatives equal in value. In other words, the indifference point should not shift. However, Experiment 2 found a significant decrease in indifference points in the delayed VI condition compared to the no VI condition.

One way to reconcile these results with the hyperbolic-decay model is to assume that the presence of the VI schedules caused Q_d , the quality of the delays, to become negative, perhaps because they now served as timeouts from periods in which reinforcers were potentially available. Computer simulations showed that if the quality of the delays is negative, the model predicts smaller indifference points in the delayed VI condition, but only if the quality of the postreinforcement time for the standard alternative (the period with only the white houselights present, as shown in Figure 5) is not equally negative. If this postreinforcement time has the same negative quality as the delays, the model predicts no difference between the delayed VI and no VI conditions.

Further research will be necessary to clarify this matter. There may be more direct ways to assess whether the delays before reinforcement become more aversive when an intertrial VI is added, such as by observing whether subjects will make escape responses to terminate stimuli associated with the delays (cf. Thompson, 1964). For now, we can simply conclude that in a self-control situation, preference for the smaller, more immediate reinforcer increases when intertrial reinforcers are available, and this effect is largest when the reinforcement schedule is present throughout each ITI.

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