

*CHOICE IN A SELF-CONTROL PARADIGM:
QUANTIFICATION OF EXPERIENCE-BASED
DIFFERENCES*

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Previous quantitative models of choice in a self-control paradigm (choice between a larger, more-delayed reinforcer and a smaller, less-delayed reinforcer) have not described individual differences. Two experiments are reported that provide additional quantitative data on experience-based differences in choice between reinforcers of varying sizes and delays. In Experiment 1, seven pigeons in a self-control paradigm were exposed to a fading procedure that increased choices of the larger, more-delayed reinforcer through gradually decreasing the delay to the smaller of two equally delayed reinforcers. Three control subjects, exposed to each of the small-reinforcer delays to which the experimental subjects were exposed, but for fewer sessions, demonstrated that lengthy exposure to each of the conditions in the fading procedure may be necessary in order for the increase to occur. In Experiment 2, pigeons with and without fading-procedure exposure chose between reinforcers of varying sizes and delays scheduled according to a concurrent variable-interval variable-interval schedule. In both experiments, pigeons with fading-procedure exposure were more sensitive to variations in reinforcer size than reinforcer delay when compared with pigeons without this exposure. The data were described by the generalized matching law when the relative size of its exponents, representing subjects' relative sensitivity to reinforcer size and delay, were grouped according to subjects' experience.

Key words: self-control, individual differences, matching law, delay of reinforcement, amount of reinforcement, key peck, pigeons

A self-control paradigm has been defined by many researchers working with animals as a choice between a larger, more-delayed rein-

forcer and a smaller, less-delayed reinforcer (e.g., Ainslie, 1974; Grosch & Neuringer, 1981; Rachlin & Green, 1972). Animals, like humans, sometimes choose the larger, more-delayed reinforcer, and sometimes the smaller, less-delayed reinforcer. Individual animal subjects exposed to identical conditions in a self-control experiment may or may not choose the larger, more-delayed reinforcer. For example, in Ainslie's (1974) experiment, pigeons could make a response that would commit them to a later choice of the larger, more-delayed reinforcer. Three out of 10 pigeons learned to make this response.

Other experiments with animals have shown that it is possible to increase the probability of subjects choosing the larger, more-delayed reinforcer by introducing the shorter or longer delays gradually (Eisenberger, Masterson, & Lowman, 1982; Fantino, 1966; Ferster, 1953; Logue & Mazur, 1981; Mazur & Logue, 1978). Mazur and Logue (1978) first gave pigeons the opportunity to choose between 6 s of food delayed 6 s, and 2 s of food delayed 6 s. The pigeons chose the 6-s reinforcer delayed 6 s. Then, over about a year's time and about

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11,000 trials, Mazur and Logue slowly decreased the delay to the 2-s reinforcer until it was 0 s. The pigeons exposed to this fading procedure (see Terrace, 1966) continued to choose the 6-s reinforcer significantly more often than did pigeons without this exposure.

Any quantitative model purporting to account for choice between reinforcers of varying sizes and delays must include individual differences. However, the two most prevalent quantitative models for describing such choices, the delay-reduction model (Fantino, 1969, 1977; Fantino & Navarick, 1974; Navarick & Fantino, 1976; Squires & Fantino 1971) and the matching law (Ainslie & Herrnstein, 1981; Rachlin, 1970, 1974, 1976; Rachlin & Green, 1972), include parameters only for the actual physical characteristics of the reinforcer (e.g., amounts, frequencies, and delays). For example, in the generalized version of the matching law (Baum, 1974b),

$$\frac{B_1}{B_2} = k \left(\frac{V_1}{V_2} \right)^a, \quad (1)$$

where B_i represents the number of choices of reinforcer i , V_i represents the value of reinforcer i (Baum & Rachlin, 1969), and the parameter k represents a response bias to choose Alternative 1 (when k is greater than 1.0), or Alternative 2 (when k is less than 1.0). The parameters k and a are often calculated using individual subjects' data, but the calculations are usually performed in this way only because data combined across subjects can yield parameter values that are quite different from any of those for the individual subjects. The purpose of these parameters has not been to describe individual differences (but see Herrnstein, 1981b, for one way in which the matching law could be modified to describe individual differences in a self-control paradigm).

At first a was assumed to deviate from 1.0 only when subjects lacked ideal information about the experiment (de Villiers, 1977). Several researchers have recently proposed that the value of a depends on the nature of the experimental situation (e.g., Davison, 1982; Keller & Gollub, 1977) and on the particular continuum (reinforcer amount, delay, frequency, etc.) represented by V_i (e.g., Herrnstein, 1981a; Rachlin, Battalio, Kagel, & Green, 1981; Wearden, 1980). The parameter a represents subjects' sensitivity to variations

in V_i (Davison, 1982). Thus, the usual matching law model for self-control,

$$\frac{B_1}{B_2} = k \left(\frac{A_1 D_2}{A_2 D_1} \right), \quad (2)$$

in which A_i represents the amount or size of reinforcer i , and D_i its delay (Ainslie, 1975; Mazur & Logue, 1978; Rachlin & Green, 1972), would become

$$\frac{B_1}{B_2} = k \left(\frac{A_1}{A_2} \right)^{s_A} \left(\frac{D_2}{D_1} \right)^{s_D}, \quad (3)$$

where s_A represents a subject's sensitivity to variations in the size of a reinforcer, and s_D its sensitivity to variations in the delay of a reinforcer (see Davison, 1982; Green & Snyderman, 1980; Hamblin & Miller, 1977; Hunter & Davison, 1982; Miller, 1976; Schneider, 1973; and Todorov, 1973, for further examples of the matching law used with more than one continuum and exponent). Except in some cases of individual subjects, Equations 1 and 2 have provided a good description of choice, including choice in a self-control paradigm, when reinforcers are qualitatively similar and are delivered according to certain schedules, notably simple or simple-concurrent ratio or interval schedules (Ainslie & Herrnstein, 1981; de Villiers, 1977; Green, Fisher, Perlow, & Sherman, 1981; Logue & Mazur, 1981; Mazur & Logue, 1978). If s_A and s_D were calculated for individual subjects, and if the values of these individually calculated exponents were found to vary predictably given specific variations in the subjects' genetic background or experience, Equation 3 could also provide an orderly account of individual subjects' data (Logue & Mazur, 1979; cf. Green & Snyderman, 1980; Ito & Asaki, 1982).

The overall purpose of the present experiments was to explore a use for the quantitative model of choice between reinforcers of varying size and delay represented by Equation 3, that of describing individual differences, through collection of additional quantitative data on experience-based differences in choice within a self-control paradigm. Experiment 1 examined the increase in choices of the larger, more-delayed reinforcer in pigeons using Mazur and Logue's (1978) fading procedure. Experiment 2 compared some of these pigeons' sensitivity to variations in reinforcer delay and reinforcer size with that of

pigeons that had not been exposed to the fading procedure.

EXPERIMENT 1

Experiment 1 had three specific purposes. The first of these was to replicate Mazur and Logue's (1978) use of their fading procedure to increase choices of the larger, more-delayed reinforcer in a self-control paradigm with pigeons. The second was to examine choice in a self-control paradigm in a control group different from the one reported in Mazur and Logue. Mazur and Logue's control subjects were exposed to only the initial and final conditions to which the experimental subjects were exposed, and thus controlled for whether any exposure to the fading procedure is necessary to increase choices of the larger, more-delayed reinforcer. The present control group controlled for the degree of exposure to the conditions of the fading procedure that is necessary to increase choices of the larger, more-delayed reinforcer. These control subjects were briefly exposed to each of the conditions to which the experimental subjects were exposed. Finally, Experiment 1 served to prepare some subjects for use in Experiment 2, in which the sensitivity to variations in reinforcer size and delay was compared in subjects with and without exposure to the fading procedure.

METHOD

Subjects

Ten adult, experimentally naive, White Carneaux pigeons, numbered 70, 71, 99, 100, 101, 102, 104, 105, 106, and 107, served in this experiment. They were maintained at 80% of their free-feeding weights. An additional subject, number 103, had to be dropped from the experiment due to illness during the fourth condition; the data from this subject are not reported below. Pigeons 100 to 102 were placed in Group A, Pigeons 104 to 107 in Group B, and Pigeons 70, 71, and 99 in Group C.

Apparatus

The experiment was conducted in three identical experimental chambers. Each chamber was 32 cm long, 32 cm wide, and 30 cm high. Two response keys were mounted on one wall, 21 cm above the floor of the chamber, 12.5 cm apart. These keys required a minimum

force of .17 N to operate and could be transilluminated red or green. A food hopper below the keys provided access to mixed grain when lit by two number 1819 bulbs and when a Plexiglas door was raised. The food hopper was also continuously lit by one 1.1-W light. A chamber could be illuminated by two 7.5-W white lights, one 7.5-W red light, or one 7.5-W green light. These lights shone through a Plexiglas-covered hole in the aluminum ceiling of the chamber. Each chamber was enclosed in a sound-attenuating box. Each box contained an air blower for ventilation that also helped to mask extraneous sounds. A PDP-8/L computer in another room, using a SUPERSKED program, controlled the stimuli and recorded responses.

Procedure

The pigeons were first trained to peck using an autoshaping procedure. The subsequent procedure was similar to that used by Mazur and Logue (1978). Each session consisted of 34 trials — 31 choice trials and 3 no-choice trials. At the beginning of each choice trial, the left key was transilluminated green and the right key was transilluminated red. The chamber was illuminated with white light. A peck on one key was followed by a feedback click, turned both keys dark, and led to a 6-s delay period, followed by a 6-s reinforcement period of access to grain. A peck on the other key was followed by a feedback click, turned both keys dark, and led to a delay period (specified below) followed by a 2-s reinforcement period. Only the green overhead light was lit during the delay and reinforcement periods following a green-key peck, and only the red overhead light was lit during the delay and reinforcement periods following a red-key peck. Pecks on dark keys were not followed by feedback and had no effect.

The no-choice trials required the pigeons to respond on the key associated with the 2-s reinforcer; only that key was lit, and pecking it led to the same sequence of events as on a choice trial. Pecks on the other key had no consequences. The no-choice trials occurred on trials 10, 20, and 30.

During intertrial intervals the white overhead lights were lit. Intertrial intervals varied so that each trial occurred 1 min after the beginning of the previous trial as long as the subject's response latency was less than 48 s.

Table 1
Order of Conditions in Experiment 1

| Delay to Small Reinforcer (sec)* | Number of Sessions | | |
|----------------------------------|--------------------|---------|---------|
| | Group A | Group B | Group C |
| 6.0 | 13 | 22 | 10 |
| 4.0 | 25 | 33 | 3 |
| 3.0 | 10 | 30 | 3 |
| 2.75 | 23 | 32 | 3 |
| 2.5 | 19 | 15 | 3 |
| 2.25 | 23 | 24 | 3 |
| 2.0 | 27 | 45 | 3 |
| 1.75 | 12 | 23 | 3 |
| 1.50 | 27 | 20 | 3 |
| 1.25 | 19 | 31 | 3 |
| 1.0 | 20 | 31 | 3 |
| .75 | — | — | 3 |
| .5 | 54 | 21 | 3 |
| .37 | — | — | 3 |
| .25 | — | — | 3 |
| .1 | 31 | 37 | 10 |
| .1 | 18 | 15 | 13 |

*The last condition was a reversal condition in which the contingencies were reversed for the two keys.

For latencies longer than 48 s, the interval between the start of two trials was a multiple of 1 min (e.g., 2 min if the response latency was between 49 s and 1 min 48 s, 3 min if the response latency was between 1 min 49 s and 2 min 48 s, etc.). Because latencies were almost always shorter than 48 s, sessions usually lasted 34 min, and the overall reinforcement rate was one reinforcer per minute, regardless of the distribution of left and right choices.

For all conditions of Group A and Group B, and for the initial and last two conditions of Group C, conditions were changed when the data satisfied a stability criterion. This criterion specified a minimum of 10 sessions in a condition. In the last five consecutive sessions, the number of large-reinforcer choices had to be neither higher nor lower than (i.e., within the range of) the number of large-reinforcer choices in all previous sessions within that condition. All members of a group had to simultaneously satisfy the stability criterion in order for the condition for that group to be changed. This ensured that all members of a group had equivalent experience. Other conditions of Group C each lasted for three sessions. Sessions were conducted 5 to 6 days per week.

For the first condition the programmed delay to the small reinforcer, the reinforcer delay following a red-key peck, was 6 s. In subsequent conditions this value was decreased in 2-, 1-, .5- (for Groups A and B only), .25-, or

.125-s steps until a delay of .1 s was reached. For the last condition the contingencies for pecking the two keys were reversed. Such a change measures a pigeon's tendency to maintain preference for a particular reinforcer when the contingencies have been switched to the opposite side, and opposite colored, keys. Table 1 summarizes the conditions, the order in which they were conducted, and the number of sessions that each was in effect.

The procedures for the pigeons in Groups A and B were identical with the exception that these pigeons participated in the experiment at two slightly different times and in two different groups so that, because of the group stability criterion, they were exposed to each condition for somewhat different numbers of sessions. Group C, the control group, was exposed to the same conditions as the fading-exposed experimental pigeons (Groups A and B), plus three additional conditions, all in the same order as the experimental pigeons. However, Group C was exposed to each of these conditions for only three sessions, instead of until a behavioral stability criterion was satisfied (with the exception of the first and last two conditions). Mazur and Logue's (1978) control group was exposed only to the initial and final conditions used for the experimental subjects, with exposure to these two conditions being continued until the behavioral stability criterion was satisfied.

RESULTS

Data used for analyses in this experiment, as well as in Experiment 2, were means from the last five sessions of each condition, with the exception of Group C conditions that were in effect for only three sessions; in those cases only the data from the last session were used. Session times were fairly constant for the ten subjects ($M = 34.8$ min, $SE = .4$). Figure 1 shows the number of large-reinforcer choices as a function of condition for Groups A, B, and C. For all three groups the number of large-reinforcer choices decreased as the delay to the small reinforcer was decreased. When this delay was smallest, .1 s, and the contingencies were reversed, Groups A and B continued to make about the same number of large-reinforcer choices, while Group C made fewer.

Figure 2 shows individual-subject data for the last two conditions, including the reversal condition, for all three groups. The striped

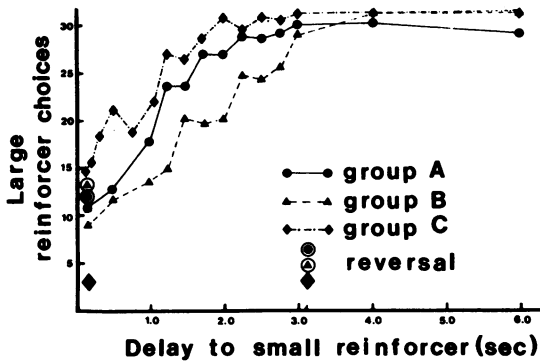


Fig. 1. The mean number of large-reinforcer choices in the last five sessions of each condition for Group A, Group B, and Group C in Experiment 1. The three unconnected points are the data for the reversal condition in which the contingencies for pecking the two keys were reversed.

bars represent the number of large-reinforcer choices in the second-to-last condition, and the open bars in the last (reversal) condition.

Figure 3 compares the mean number of large-reinforcer choices over the last two conditions (the last fading and the reversal conditions) for all three groups with the data obtained from the fading-exposed subjects in the comparable conditions in Mazur and Logue (1978). These means measure self-control with position bias canceled out ($[(\text{last fading} + \text{reversal})/2 = [(\text{self-control} + \text{bias}) + (\text{self-control} - \text{bias})]/2 = \text{self-control}]$). Also presented in Figure 3 are the data from the last condition for Mazur and Logue's (1978) control subjects, subjects exposed only to the initial (6 s) and final (0 s) conditions without the intervening fading experience. These subjects were never exposed to a reversal condition. The difference between Groups A ($M = 10.9, SE = 1.7, N = 3$) and B ($M = 10.3, SE = 2.7, N = 4$) is not significant ($t[5] = .15, p > .8$), nor between those two groups combined ($M = 10.5, SE = 1.7, N = 7$) and the Mazur and Logue fading-exposed subjects ($M = 17.3, SE = 4.5, N = 4$; $t(9) = -1.51, .1 < p < .2$). The difference between Group C ($M = 8.9, SE = 2.7, N = 3$) and the Mazur and Logue control group ($M = .8, SE = .6, N = 4$) is significant ($t[5] = 2.79, .02 < p < .05$), with Group C's large-reinforcer choices approaching those of Groups A and B, largely due to the data of Pigeon 71. The mean for this pigeon may have been inflated because this bird never pecked the right key and is therefore likely to have had a large position bias and no self-control whatsoever. In cases

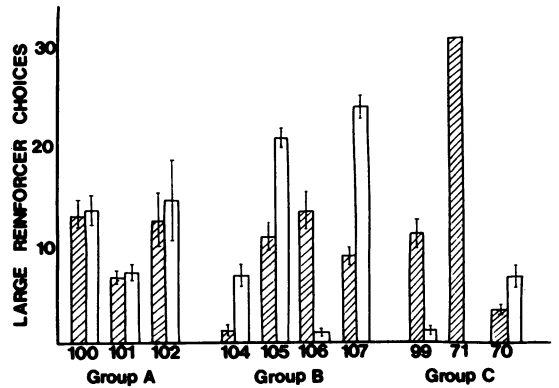


Fig. 2. The mean number of large-reinforcer choices in the last five sessions of the second-to-last (striped bars) and last (reversal, open bars) conditions in Experiment 1. Results are shown individually for each pigeon. The vertical lines depict one standard error on each side of the mean.

in which a position bias is larger than the self-control present, the mean of the last two conditions will be artificially inflated because the

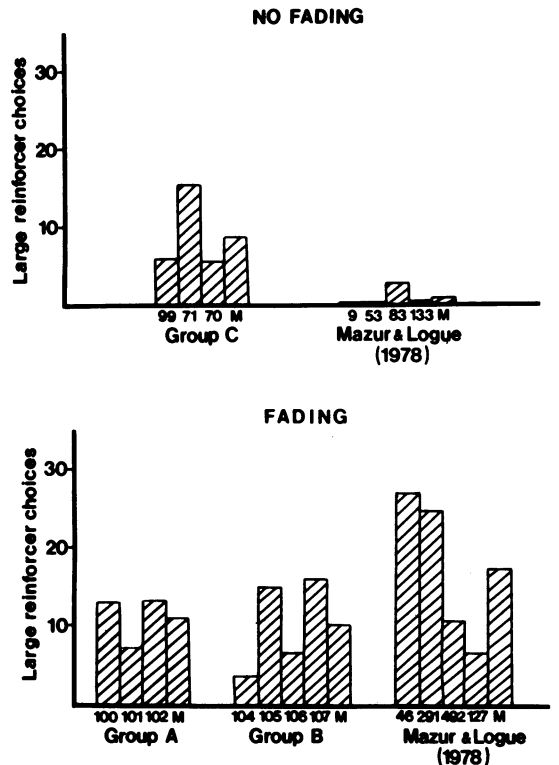


Fig. 3. The mean number of large-reinforcer choices in the last two conditions for all subjects in Experiment 1 and the fading-exposed subjects in Mazur and Logue (1978), and in the last condition for the nonfading-exposed subjects in Mazur and Logue (1978). Individual and group results are shown.

number of large-reinforcer choices in the reversal condition cannot be less than zero.

It is possible to estimate the direction of a subject's position bias by subtracting the mean of its large-reinforcer choices in the last fading and the reversal conditions from its number of large-reinforcer choices in the last fading condition. Over all fading-exposed subjects this value is -1.0 ($SE = 1.2$, $N = 7$), indicating a position bias in the last fading condition to respond on the key that delivered the small reinforcer (the right key). The value for Group C (nonfading-exposed subjects) is larger and in the opposite direction, $+ 6.1$ ($SE = 4.2$, $N = 3$).

DISCUSSION

The results depicted in Figures 1, 2, and 3 indicate that Mazur and Logue's (1978) results with the fading procedure were replicated here. The fading procedure does increase the number of larger, more-delayed reinforcers chosen in a self-control paradigm. In addition, results from Group C suggest that substantial exposure to the intervening conditions of the fading procedure may be necessary for this to occur; three sessions per condition may not be sufficient. While Group C appeared to frequently choose the larger, more-delayed reinforcer, even after the delay to the smaller reinforcer was decreased to .1 s in the second-to-last condition, reversing the contingencies for pecking the two keys suggested that a position bias for the left key, probably due to hysteresis (Stevens, 1957), was largely responsible (Figures 1 and 2). Pigeon 71 made all of its pecks on the left key in both the second-to-last and reversal conditions. However, Pigeon 70 chose about the same number of larger, more-delayed reinforcers as the lower range of the fading-exposed pigeons (Figures 2 and 3). The individual differences within all of the groups suggest that different degrees of fading may be necessary to increase the number of larger, more-delayed reinforcers chosen by individual subjects.

EXPERIMENT 2

Pigeons which have been exposed to the fading procedure are relatively more sensitive to reinforcer size than reinforcer delay when compared with pigeons lacking this exposure and when Mazur and Logue's (1978) trials pro-

cedure is used. The present experiment examined whether pigeons with these two types of experience would also demonstrate differential sensitivity to reinforcer size and reinforcer delay when reinforcers were programmed according to a concurrent variable-interval variable-interval (VI VI) schedule. On such a schedule differential sensitivity to reinforcer size and reinforcer delay can be compared using Equation 3. If either reinforcer size or reinforcer delay is varied, and the logarithm of Equation 3 is taken, then in the first case

$$\log(B_1/B_2) = s_A \log(A_1/A_2) + \log k, \quad (4)$$

and in the second case,

$$\log(B_1/B_2) = s_D \log(D_2/D_1) + \log k. \quad (5)$$

Thus the exponents s_A and s_D are the slopes of straight-line equations fit to the data in logarithmic coordinates.

Since the matching law has difficulty accounting for behavior on concurrent-chain as compared with simple concurrent schedules (e.g., Dunn & Fantino, 1982; Gentry & Marr, 1980; Gibbon, 1977; Green & Snyderman, 1980; Williams & Fantino, 1978), the schedule used in the present experiment was designed to be as much like a simple concurrent schedule as possible, given the reinforcers were of necessity delayed. As in Experiment 1, in which a reinforcer followed each response on a lit key, responding until an actual choice for one or the other reinforcer was kept at a minimum. Further, a 3-s changeover delay was employed in the present experiment, a technique which increases the chances of preference in the initial link of a concurrent chain being similar to preference in a simple concurrent schedule (Baum, 1974a; Davison, 1983).

METHOD

Subjects

Seven adult White Carneaux pigeons served in this experiment. Three of these pigeons were numbers 100, 101, and 102 that constituted Group A in Experiment 1. These pigeons were chosen from Experiment 1 for the present experiment because their self-control behavior was consistent and not a result of position or color biases (see Figure 2). The other four pigeons used in the present experiment, numbers 67, 56, 61, and 62, had previously been exposed to concurrent VI schedules, but not the fading procedure. All of the

subjects were maintained at 80% of their free-feeding weights.

Apparatus

The same apparatus was used as in Experiment 1.

Procedure

All subjects were placed on concurrent, independent, VI 30-s VI 30-s schedules. Pecks on the left, green key were reinforced according to one VI schedule, while pecks on the right, red key were reinforced according to the other VI schedule. The VI schedules were constructed according to the progression suggested by Fleshler and Hoffman (1962). A 3-s changeover delay (COD) was in effect; 3 s had to elapse after a changeover response from the left to the right key or vice versa, or after the first response following reinforcement, before a subsequent key peck could deliver a reinforcer. The purpose of the COD was to decrease the probability of reinforcement of sequences of responses involving both keys. In order to keep reinforcer frequency as constant as possible between the two alternatives so that reinforcer frequency would not affect choice, both VI schedules ran continuously during a session. Each time an interval in one of the VI schedules timed out, the schedule continued but a counter representing reinforcers available from that VI schedule was incremented. Each time a reinforcer was received the appropriate counter was decremented.

At the beginning of a session the left key was transilluminated green, the right key red, and the chamber was illuminated white. A peck on a lit key could produce a reinforcer so long as the counter for the VI schedule for that key had a value of at least one and the COD had been satisfied. When a reinforcer was received for a left peck, both keys and the overhead white lights were darkened and the green overhead light was illuminated for the delay period, followed by the reinforcement period of access to grain. At the end of the reinforcement period the white overhead light and the key lights were again illuminated. The sequence of events for reinforcement following a right peck was similar except that a red, instead of a green, overhead light was used. Pecks were followed by feedback when the keys were lit; pecks on darkened keys had no effect. Sessions were terminated after a total

Table 2
Order of Conditions in Experiment 2

| Reinforcer parameters (sec) | Number of sessions | | | | | | | | | | |
|-------------------------------------------------------------|--------------------------------|-----|-----|----|----|-----------------------------------|----|--|--|--|--|
| | Fading- exposed subjects | | | | | Nonfading- exposed subjects | | | | | |
| A ₁ A ₂ D ₁ D ₂ | 100 | 101 | 102 | 67 | 56 | 61 | 62 | | | | |
| 6 6 6 6 | 14 | 13 | 11 | 14 | 16 | 20 | 18 | | | | |
| 10 2 6 6 | 16 | 19 | 14 | 15 | 25 | 19 | 31 | | | | |
| 6 6 10 2 | 11 | 25 | 14 | 27 | 13 | 12 | 20 | | | | |
| 2 10 6 6 | 24 | 14 | 22 | 10 | 10 | 20 | 14 | | | | |
| 6 6 2 10 | 18 | 10 | 28 | 24 | 24 | 19 | 13 | | | | |

Note: Alternative 1 corresponds to the left key and Alternative 2 to the right key.

of 35 reinforcers had been received and were conducted 5 to 6 days per week.

A subject was exposed to a condition until it satisfied the stability criterion, using left/right pecks as the dependent variable. Table 2 shows the conditions used, the order in which they were conducted, and the number of sessions that each condition was in effect for each subject. Because procedural variations can disrupt the effects of the fading procedure (see Logue & Mazur, 1981), subjects were exposed to only two conditions in which reinforcer sizes were varied and two in which reinforcer delays were varied, and one in which neither was varied, that being the minimum number of conditions with which sensitivity to reinforcer size and reinforcer delay could be assessed. However, because Pigeon 100 demonstrated a strong right bias during the first four conditions of the present experiment, essentially never being exposed to the contingencies for left pecks, that subject was exposed to the conditions a second time after its bias had disappeared. The data for Pigeon 100 from only this second set of conditions are reported below.

Results

The means and standard errors (in parentheses) of left and right time spent pecking per session, left and right peck response and overall and local reinforcer rates per minute, and session time are shown for each subject and condition in Table 3. Time spent pecking is defined as the cumulative time from a peck on one key until a peck on the other key or the start of reinforcement. Peck and overall reinforcer rates per minute are calculated using session time minus reinforcer and reinforcer

Table 3
Mean response rates, time pecking, overall and local reinforcer rates, and session time in Experiment 2.

| Condition (A ₁ A ₂ D ₁ D ₂) | Peck response rates per min | | Time pecking per session (min) | | Overall reinforcer rates per min | | Local reinforcer rates per min | | Session time (min) |
|-----------------------------------------------------------------------------|-----------------------------|------------|--------------------------------|-----------|----------------------------------|-----------|--------------------------------|-----------|--------------------|
| | left | right | left | right | left | right | left | right | |
| Fading-exposed subjects | | | | | | | | | |
| 100 | | | | | | | | | |
| 6,6,6,6 | 40.2(9.0) | 30.3(3.4) | 2.4(.6) | 1.6(.8) | 1.8(1.7) | 2.1(1.0) | 8.6(1.6) | 15.3(2.5) | 10.7(2.4) |
| 10,2,6,6 | 58.2(4.3) | 10.6(.6) | 3.2(.1) | .6(.1) | 4.2(.2) | 1.6(.1) | 8.0(.2) | 16.3(1.3) | 14.1(.2) |
| 6,6,10,2 | 35.9(7.3) | 6.1(2.5) | 2.3(.3) | .4(.1) | 3.3(.4) | .9(.4) | 13.5(2.0) | 16.3(2.1) | 18.5(2.6) |
| 2,10,6,6 | 4.3(1.9) | 41.1(5.1) | .4(.1) | 3.6(.4) | .4(.1) | 3.6(.4) | 10.1(3.1) | 9.3(.9) | 18.2(1.2) |
| 6,6,2,10 | 75.0(1.2) | 12.2(1.4) | 4.1(.3) | .9(.1) | 3.8(.1) | 1.9(.2) | 6.0(.4) | 12.8(1.5) | 12.4(.2) |
| 101 | | | | | | | | | |
| 6,6,6,6 | 18.5(1.8) | 38.1(3.4) | 1.1(.2) | 1.8(.2) | 2.6(.2) | 4.0(.3) | 13.3(1.6) | 12.2(1.6) | 12.5(.4) |
| 10,2,6,6 | 65.8(4.5) | 2.4(.7) | 6.8(.3) | .2(.1) | 4.0(.2) | .3(.1) | 4.8(.2) | 15.6(3.2) | 14.0(3.2) |
| 6,6,10,2 | 14.3(1.4) | 78.1(1.6) | 1.5(.2) | 3.6(.1) | 1.9(.2) | 3.8(.1) | 9.0(2.2) | 6.5(.3) | 12.4(.2) |
| 2,10,6,6 | 13.3(3.6) | 60.7(6.8) | .8(.1) | 3.6(.1) | 1.4(.1) | 4.0(.4) | 12.9(2.1) | 7.2(.4) | 15.1(.8) |
| 6,6,2,10 | 80.5(16.1) | 21.8(5.7) | 4.4(.2) | .9(.1) | 3.7(.2) | 1.5(.2) | 5.3(.2) | 12.6(2.0) | 12.8(.3) |
| 102 | | | | | | | | | |
| 6,6,6,6 | 13.6(3.1) | 21.6(2.0) | .7(.1) | 2.7(.4) | 1.5(.4) | 3.3(.2) | 15.5(.9) | 9.8(1.2) | 14.3(.4) |
| 10,2,6,6 | 47.7(2.7) | 10.8(.8) | 2.3(.2) | .6(.03) | 4.5(.2) | 1.6(.1) | 11.3(1.1) | 14.6(1.4) | 13.8(.2) |
| 6,6,10,2 | 19.9(1.3) | 43.8(2.6) | .8(.1) | 3.7(.2) | 1.7(.1) | 3.7(.1) | 14.1(1.6) | 5.4(1.3) | 12.6(.2) |
| 2,10,6,6 | 9.6(1.4) | 54.1(2.1) | .4(.1) | 3.3(.2) | .9(.1) | 4.5(.3) | 16.3(1.9) | 6.9(.1) | 15.3(.2) |
| 6,6,2,10 | 49.3(3.4) | 12.9(1.9) | 3.5(.4) | .7(.1) | 3.5(.1) | 1.3(.2) | 7.8(1.1) | 15.2(2.0) | 13.3(.3) |
| Nonfading-exposed subjects | | | | | | | | | |
| 67 | | | | | | | | | |
| 6,6,6,6 | 40.3(7.3) | 18.4(3.4) | 2.2(.3) | 1.6(.3) | 3.1(.5) | 1.4(.4) | 9.7(.9) | 10.9(.8) | 14.9(.5) |
| 10,2,6,6 | 36.5(3.0) | 5.0(.8) | 3.0(.3) | .4(.1) | 3.9(.1) | .3(.1) | 11.4(1.3) | 5.7(1.5) | 17.4(.2) |
| 6,6,10,2 | 5.6(1.7) | 64.4(1.9) | .4(.1) | 7.8(1.1) | .6(.2) | 2.8(.1) | 16.1(2.8) | 3.9(.4) | 16.1(.7) |
| 2,10,6,6 | 8.6(2.1) | 62.5(4.0) | .4(.1) | 3.6(.7) | .8(.2) | 4.5(.2) | 14.4(1.8) | 9.3(1.4) | 15.6(.8) |
| 6,6,2,10 | 61.8(2.2) | 1.3(.3) | 10.9(.4) | .2(.1) | 2.6(.04) | .1(.02) | 3.2(.1) | 8.4(2.1) | 17.6(.3) |
| 56 | | | | | | | | | |
| 6,6,6,6 | 85.0(16.8) | 26.3(3.1) | 2.4(.3) | 1.0(.2) | 4.6(.5) | 2.8(.4) | 9.6(.8) | 14.2(2.2) | 12.0(.5) |
| 10,2,6,6 | 77.2(6.6) | 5.2(1.8) | 4.5(.6) | .3(.1) | 4.3(.2) | 1.2(.7) | 7.5(1.0) | 11.8(2.4) | 16.3(.5) |
| 6,6,10,2 | 29.6(2.8) | 64.2(3.2) | 1.2(.1) | 3.2(.3) | 2.4(.2) | 3.8(.1) | 10.0(2.6) | 6.8(.5) | 12.2(.2) |
| 2,10,6,6 | 24.1(.9) | 55.1(2.7) | .9(.04) | 2.6(.2) | 2.1(.4) | 4.2(.7) | 13.1(1.3) | 9.2(.7) | 12.7(.3) |
| 6,6,2,10 | 75.3(3.2) | 7.6(1.5) | 7.4(.9) | .5(.1) | 3.3(.2) | .7(.2) | 4.3(.4) | 11.4(2.4) | 14.6(.7) |
| 61 | | | | | | | | | |
| 6,6,6,6 | 42.0(5.5) | 69.0(3.2) | .9(.2) | 2.3(.3) | 3.1(.5) | 3.7(.2) | 43.8(29.3) | 8.9(1.2) | 12.3(.4) |
| 10,2,6,6 | 96.5(5.0) | 24.7(2.5) | 3.0(.1) | .9(.1) | 5.0(.2) | 1.9(.2) | 8.6(.3) | 11.4(1.3) | 13.2(.2) |
| 6,6,10,2 | 9.8(1.2) | 93.2(2.1) | .4(.03) | 7.4(.3) | .8(.1) | 3.2(.1) | 16.8(.7) | 3.9(.2) | 14.6(.3) |
| 2,10,6,6 | 14.3(1.3) | 78.3(2.3) | .4(.04) | 3.5(.1) | 1.1(.1) | 4.5(.2) | 17.4(1.9) | 8.1(.3) | 14.6(.3) |
| 6,6,2,10 | 97.6(4.6) | 22.4(1.7) | 3.9(.7) | .7(.1) | 4.0(.1) | 1.9(.1) | 6.1(1.4) | 16.2(1.5) | 12.2(.1) |
| 62 | | | | | | | | | |
| 6,6,6,6 | 69.6(4.5) | 24.7(4.0) | 3.0(.5) | .8(.1) | 4.1(.1) | 1.8(.4) | 8.8(1.0) | 12.3(1.0) | 13.1(.4) |
| 10,2,6,6 | 90.9(2.1) | .3(.2) | 5.6(.3) | .02(.01) | 3.9(.1) | .1(.003) | 6.3(.3) | 3.6(3.6) | 17.9(.3) |
| 6,6,10,2 | 4.8(.4) | 109.6(2.7) | .4(.1) | 8.9(.3) | 3.6(.03) | 2.8(.1) | 12.2(2.5) | 3.5(.1) | 16.3(.3) |
| 2,10,6,6 | 7.4(1.9) | 73.3(4.2) | .4(.1) | 3.9(.2) | .4(.1) | 4.1(.1) | 8.0(2.5) | 8.3(.5) | 16.7(.1) |
| 6,6,2,10 | 109.0(1.4) | 12.7(5.9) | 7.6(1.3) | .4(.2) | 3.2(.3) | .8(.4) | 4.3(.7) | 13.5(.7) | 14.9(1.0) |

Note: Means and standard errors (in parentheses) are shown.

delay time as the time base. Local reinforcer rates use time spent pecking on a given key as the time base.

One aim of the procedure, to keep the time

responding fairly short so as to increase the control over behavior by the reinforcer sizes and delays as opposed to the total time until reinforcement, appears to have been success-

ful. Combining data from both keys and all seven pigeons, the mean time between reinforcers when the key lights were on was only 8.3 s ($SE = .01$, $N = 7$), and the mean number of pecks per reinforcer was only 15.6 ($SE = 1.7$, $N = 7$).

Another aim of the procedure was to keep relative reinforcer rates fairly constant. Although overall reinforcer rates were not constant between the two sides, Table 3 shows that these rates were closer than either the peck or time-spent-pecking rates. Combined data across all conditions for the seven subjects show the absolute differences from 1.0 in log units for the mean relative (left/right) peck, time spent pecking, and overall reinforcer rates were .99 ($SE = .15$, $N = 7$), .92 ($SE = .10$, $N = 7$), and .62 ($SE = .076$, $N = 7$), respectively. All relative rate means are geometric means. Differences from 1.0 were calculated by taking the mean absolute difference of the logs of the relative rates from 0. Further, as indicated by the local reinforcer rates, when a subject did respond on its nonpreferred side, the reinforcer rate tended to be higher than on its preferred side. Combined data across all conditions reveal that mean relative local reinforcer rate absolute differences for the seven pigeons were close to zero (in log units, $M = .25$, $SE = .014$, $N = 7$).

In the present experiment the VI schedules timed continuously and available reinforcers were accumulated. Thus, whenever a pigeon spent a few seconds pecking at a key it was likely to receive a reinforcer, time between received reinforcers was short, relative overall reinforcer rates were necessarily a direct function of preference, and relative local reinforcer rates varied slightly and in the opposite direction from preference. Since relative local reinforcer rates have been found to be more predictive of preference than overall rates (e.g., Hinson & Staddon, 1983; Williams, 1983), relative reinforcer rates are unlikely to be responsible for the relative preferences observed here. Nevertheless, the covariation between relative preference and relative overall reinforcer rates may present a problem in the interpretation of the results.

Another way of ensuring that reinforcer frequency remained equal for the two alternatives would have been to use interdependent concurrent VI schedules (Stubbs & Pliskoff, 1969). In such a procedure there is only one

timer that times one set of intervals, randomly allotted to either the left or the right response alternative. Because the timer stops timing whenever an interval has timed out and a reinforcer is scheduled, not resuming until the reinforcer has been obtained, a subject must receive each programmed reinforcer in turn, be it on the subject's preferred or nonpreferred side, before the subject can receive further reinforcers. Therefore, the interdependent-VI procedure can generate responding that is more similar across the two alternatives than is generated by independent VI schedules (de Villiers, 1977). Because the purpose of the present experiment was to assess sensitivity to reinforcer sizes and delays as precisely as possible, and because in the present procedure responding can vary widely as a function of the nature of the reinforcers available while leaving reinforcer frequency fairly constant, it was decided to use the present procedure rather than interdependent concurrent VI schedules.

Figures 4 and 5 show the data for Pigeons 100, 101, and 102, and Figures 6 and 7 show the data for Pigeons 67, 56, 61, and 62, plotted according to Equations 4 and 5, first with pecks and then with time spent pecking as the dependent variable. In each figure the equation for the best fitting line, calculated according to the method of least squares, is given in linear coordinates, i.e., Equation 3 with either

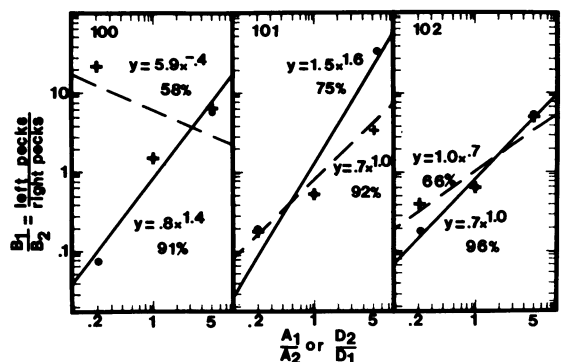


Fig. 4. The ratios of left to right pecks as a function of the ratios of left to right reinforcer amounts and reinforcer delays for each of the fading-exposed pigeons in Experiment 2. The solid and dashed lines represent the best fitting lines according to the method of least squares for the conditions in which relative reinforcer amounts and the conditions in which relative reinforcer delays were varied, respectively. The equations for these lines are shown in linear coordinates. An adjusted value of the percentage of the variance accounted for by each line is also shown.

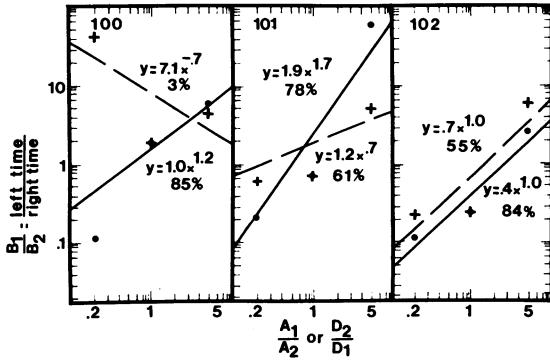


Fig. 5. The ratios of left to right time spent pecking as a function of the ratios of left to right reinforcer amounts and reinforcer delays for each of the fading-exposed pigeons in Experiment 2. The solid and dashed lines represent the best fitting lines according to the method of least squares for the conditions in which relative reinforcer amounts and the conditions in which relative reinforcer delays were varied, respectively. The equations for these lines are shown in linear coordinates. An adjusted value of the percentage of the variance accounted for by each line is also shown.

$A_1 = A_2$ or $D_1 = D_2$). An adjusted value of r^2 is also given for each equation. The formula used here attempts to compensate for the sometimes artificially high values of r^2 generated by small samples (Kerlinger & Pedhazur, 1973, pp. 282-284). The adjusted values of r^2 show that Equations 4 and 5 fit the data well; almost all of these values are above .6. The direction

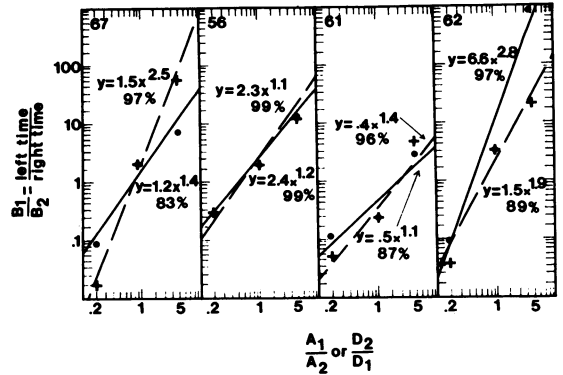


Fig. 7. The ratios of left to right time spent pecking as a function of the ratios of left to right reinforcer amounts and reinforcer delays for each of the nonfading-exposed pigeons in Experiment 2. The solid and dashed lines represent the best fitting lines according to the method of least squares for the conditions in which relative reinforcer amounts and the conditions in which relative reinforcer delays were varied, respectively. The equations for these lines are shown in linear coordinates. An adjusted value of the percentage of the variance accounted for by each line is also shown.

of the response bias shown by a subject, whether to the left as indicated by a value of k more than 1.0, or to the right as indicated by a value less than 1.0, is generally consistent across conditions in which amounts and delays were varied and pecks and time spent pecking were measured. A bias to the left was shown more often than a bias to the right.

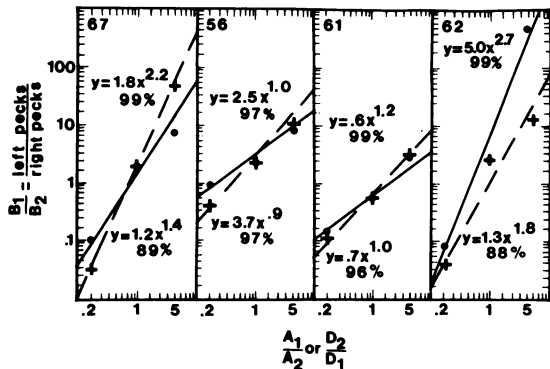


Fig. 6. The ratios of left to right pecks as a function of the ratios of left to right reinforcer amounts and reinforcer delays for each of the nonfading-exposed pigeons in Experiment 2. The solid and dashed lines represent the best fitting lines according to the method of least squares for the conditions in which relative reinforcer amounts and the conditions in which relative reinforcer delays were varied, respectively. The equations for these lines are shown in linear coordinates. An adjusted value of the percentage of the variance accounted for by each line is also shown.

Calculating for each subject the ratio of the reinforcer-size and reinforcer-delay exponents (s_A/s_D) gives the relative sensitivity of each subject to reinforcer size and reinforcer delay. Table 4 presents these calculations. The value of s_A/s_D is negative for Pigeon 100 in the present experiment because of a negative slope in the line fit to the varying reinforcer delays. This negative slope resulted from the smallest delay ratio generating the largest response ratio in that subject. As discussed above, this subject exhibited substantial response bias in some of the prior conditions. If this one point is eliminated, s_A for this subject is .9, and s_A/s_D is then 1.4, much closer to the other two subjects. But even if this point is not eliminated, the large value of s_A/s_D , regardless of whether it is positive or negative, indicates that amounts were more potent than delays in describing the behavior of this subject. There is no overlap between the values of s_A/s_D , calculated using pecks, for pigeons in this experi-

Table 4
Values of s_A and s_D in Experiment 2

| Subject | Pecks | | | Time spent pecking | | |
|----------------------------|-------|-------|-----------|--------------------|-------|-----------|
| | s_A | s_D | s_A/s_D | s_A | s_D | s_A/s_D |
| Fading-exposed subjects | | | | | | |
| 100 | 1.4 | -.4 | 3.4 | 1.2 | -.7 | 1.8 |
| 101 | 1.6 | 1.0 | 1.7 | 1.7 | .7 | 2.4 |
| 102 | 1.0 | .7 | 1.5 | 1.0 | 1.0 | 1.0 |
| median | 1.4 | .7 | 1.7 | 1.2 | .7 | 1.8 |
| Nonfading-exposed subjects | | | | | | |
| 67 | 1.4 | 2.2 | .6 | 1.4 | 2.5 | .6 |
| 56 | .9 | 1.0 | .9 | 1.2 | 1.1 | 1.1 |
| 61 | 1.0 | 1.2 | .8 | 1.1 | 1.4 | .7 |
| 62 | 2.7 | 1.8 | 1.4 | 2.8 | 1.9 | 1.5 |
| median | 1.2 | 1.5 | .9 | 1.3 | 1.7 | .9 |

ment with and without self-control training. There is some overlap in the values of s_A/s_D for fading- and nonfading-exposed subjects calculated using time spent pecking instead of pecks, although the medians are almost identical to those calculated using pecks.

DISCUSSION

The values of s_A and s_D were often higher than those found in traditional concurrent VI VI experiments (Baum, 1979; de Villiers, 1977; Wearden & Burgess, 1982). Relative preference tended to be more extreme than relative reinforcement, thus generating higher exponents than traditional concurrent VI schedules, because the present procedure used VI schedules that timed continuously and because reinforcers were saved until a subject obtained them (see Davison, 1982).

Reinforcer amounts were more potent than delays in describing the behavior of the pigeons with fading-procedure exposure. For all three of these pigeons s_A was 1.0 or greater, while s_D was 1.0 or smaller, with s_A/s_D equal to 1.0 or more using either pecks or time spent pecking to measure preference. In comparison, for Pigeons 67, 56, 61, and 62, the values of s_A/s_D were generally smaller, indicating that, as in Experiment 1 (see also Logue & Mazur, 1981; Mazur & Logue, 1978), amounts were relatively less potent than delays in describing the behavior of these pigeons without fading experience.

The data available in the present experiment suggest that s_A/s_D is larger for the fading-exposed pigeons because of a smaller value of

s_D while s_A is about the same. Using pecks and time spent pecking to measure preferences, the median values of s_A for the fading-exposed pigeons are 1.4 and 1.2, respectively, and for the nonfading-exposed pigeons they are 1.2 and 1.3. The median values of s_D for the fading-exposed pigeons are .7 and .7; for the nonfading-exposed pigeons they are 1.5 and 1.7.

The effect of the fading procedure is probably related to the presence of the green and red delay-interval lights, because without these lights the number of larger, more-delayed reinforcer choices decreases in fading-exposed pigeons (Logue & Mazur, 1981). These results are therefore consistent with data indicating that humans or other animals who perform distracting tasks, are told to think fun thoughts, or who fall asleep, show increased choice of the larger, more-delayed reinforcer in a self-control paradigm and report that time seems to go faster (Grosch & Neuringer, 1981; Hicks, Miller, Gaes, & Bierman, 1977; Hicks, Miller, & Kinsbourne, 1976; Mischel, 1981; Mischel & Ebbesen, 1970). The delay-interval lights could function as distractors for fading-exposed pigeons as described by the lower value of s_D .

Some additional confirming data can be added here. Actual time eating and actual reinforcer delay (programmed delay plus latency to eat) were also recorded in the present experiment using a photocell. The values of s_A and s_D were also calculated using these actual (though not necessarily functional) reinforcer values and multiple regression. For the fading-exposed pigeons the median values for s_A were 1.2 (pecks) and 1.1 (time pecking), for s_D .8 (pecks) and .8 (time pecking), and for s_A/s_D 1.2 (pecks) and 1.9 (time pecking). For the nonfading-exposed pigeons the median values for s_A were .8 (pecks) and 1.0 (time pecking), for s_D 1.5 (pecks) and 1.7 (time pecking), and for s_A/s_D .5 (pecks) and .5 (time pecking). As with the calculations using programmed reinforcer values, the present values of s_A/s_D are higher for the fading-exposed than the nonfading-exposed pigeons, and this seems to be more due to a difference in s_D than s_A .

GENERAL DISCUSSION

Experiment 1 confirmed that pigeons can be trained using the fading procedure to be relatively more sensitive to reinforcer size than

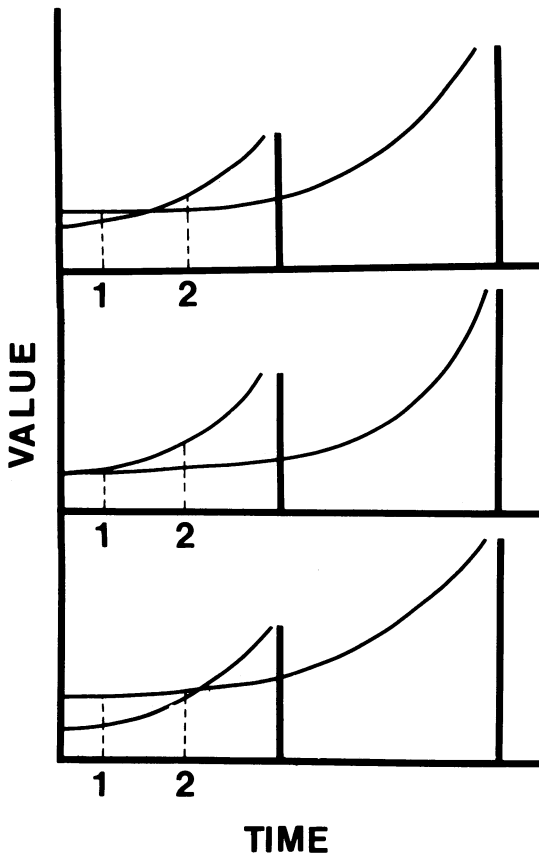


Fig. 8. The top panel shows hypothetical gradients of the value of two reinforcers as a function of time: a larger reinforcer received more distant in time, and a smaller reinforcer received nearer in time. The middle panel shows the same situation when reinforcer value declines more quickly as a function of delay. The bottom panel shows the same situation when reinforcer value declines more slowly as a function of delay.

reinforcer delay when compared with pigeons without this training. Experiment 2 showed that this training can generalize to a different schedule of reinforcement. In addition, Equations 4 and 5 provided an orderly description of the data in Experiment 2 with fading-exposed pigeons tending to show values of s_A/s_D greater than those of nonfading-exposed pigeons, probably due to a decrease in s_D . These results suggest that s_A/s_D may be useful in characterizing subject differences in a self-control paradigm.

Figure 8 is a hypothetical diagram of reinforcer value as a function of time until receipt of two separate reinforcers derived from Equation 3. In each panel there are two vertical solid lines. These lines represent the times at

which a smaller, less-delayed reinforcer (on the left) and a larger, more-delayed reinforcer (on the right) are actually received. The curves indicate how the value of these reinforcers decreases as one moves backwards in time, to the left, increasing the delay until the time at which the reinforcers are received.

In the top panel the parameters s_A and s_D are both equal to 1.0. This panel represents what the original matching law (Equation 2) would predict. At point 1 in this panel the larger reinforcer has a higher value of V_i , so the larger reinforcer will be chosen over the smaller reinforcer. At point 2 the opposite is true, demonstrating the well known self-control paradigm reversal phenomenon. Subjects are more likely to choose the smaller reinforcer if it is available immediately than if the smaller reinforcer is somewhat delayed. In the middle panel $s_A < s_D$ and the crossover point, the point at which the value of the two reinforcers is equal, shifts to the left. This means that there is now a greater time period during which the smaller reinforcer will be chosen over the larger reinforcer; now the smaller, less-delayed reinforcer is preferred at both points 1 and 2. In the bottom panel $s_A > s_D$ and the opposite occurs. The crossover point shifts to the right, later in time, and the larger, more-delayed reinforcer is preferred at both points 1 and 2.

If Equation 4 and Figure 8 accurately describe choice in a self-control paradigm, then the crossover point in a self-control experiment, the point at which a subject is indifferent between a smaller, less-delayed and a larger, more-delayed reinforcer, should be a function of s_A and s_D . From Equation 3, given $B_1 = B_2$ and assuming no response bias ($k = 1.0$), a reasonable assumption given the small amount of bias found in the subjects in Experiment 1 that were exposed to each condition until their behavior was stable (i.e., Groups A and B):

$$\frac{s_A}{s_D} = \frac{\log\left(\frac{D_1}{D_2}\right)}{\log\left(\frac{A_1}{A_2}\right)}. \quad (6)$$

Therefore, examination of the location of the crossover point makes it possible to determine s_A/s_D for pigeons in discrete-trial procedures. Then s_A/s_D for the pigeons in Experiment 2 can be compared with the same pigeons in

Experiment 1, and with pigeons that have been exposed, also until behavioral stability was reached, to conditions similar to those in Experiment 1 but either with or without the conditions in a sequence comparable to the fading procedure. (All experiments that could be identified as possessing these latter characteristics were used: Ainslie & Herrnstein, 1981; Green et al., 1981; Mazur & Logue, 1978.)

Table 5 presents the calculations of s_A/s_D using both the crossover point method (Equation 6) and the slopes method (Equations 4 and 5) for data collected from pigeons in discrete-trial and concurrent VI VI schedules, respectively. Linear interpolation was used to obtain the crossover points. First, for each subject, the two data points that spanned indifference between the larger and smaller reinforcers were identified. The data collected for each subject during discrete-trial procedures contained at most only one such pair of points. Next, the line between these two points was used to estimate the delay to the smaller reinforcer that would yield indifference between that reinforcer and the larger, 6-s, reinforcer delayed 6 s (the crossover point). If a subject never crossed over, the delay at which it made the smallest number of large-reinforcer choices was assumed to be the crossover point (note that this underestimates s_A/s_D). Once the crossover point was identified, s_A/s_D could be calculated using the reinforcer sizes and delays corresponding to that point.

Table 5 shows first that, for the data calculated using the crossover point method, s_A/s_D tends to be larger for subjects with fading-procedure exposure. This difference is significant using a Mann-Whitney U Test ($U[10,11] = 6$, $p < .002$). Second, the values of s_A/s_D obtained in Experiments 1 and 2 for Pigeons 100, 101, and 102, pigeons with fading experience, using different schedules of reinforcement and different methods for calculating s_A/s_D , are comparable. Finally, note that Green and Snyderman's (1980) data for nonfading-exposed pigeons in a concurrent-chain procedure were best fit by a value for s_A/s_D of .7, similar to the values for the other nonfading-exposed pigeons in Table 5 (see also Ito & Asaki, 1982). Thus, for these data taken as a whole, s_A/s_D is larger for pigeons with than without fading-procedure exposure and this finding has at least some cross-situational generality. Indeed, using different power functions in order to

Table 5

Summary of the values of s_A/s_D for all of the experiments.

| Experiment (and Method ^a) | Subject ^b | Time Pecking | |
|------------------------------------------|----------------------|--------------|-------------|
| | | $ s_A/s_D $ | $ s_A/s_D $ |
| Fading-exposed subjects | | | |
| 1A (C) | 100 | 2.7 | — |
| | 101 | 1.8 | — |
| | 102 | 1.5 | — |
| | median | 1.8 | — |
| 1B (C) | 104 | .7 | — |
| | 105 | 1.5 | — |
| | 106 | 3.1 | — |
| | 107 | 1.4 | — |
| | median | 1.4 | — |
| Mazur & Logue (1978) (C) | 46 | 1.3 | — |
| | 291 | 1.1 | — |
| | 492 | 1.3 | — |
| | 127 | 1.5 | — |
| | median | 1.3 | — |
| 2 (S) | 100 | 3.4 | 1.8 |
| | 101 | 1.7 | 2.4 |
| | 102 | 1.5 | 1.0 |
| | median | 1.7 | 1.8 |
| Nonfading-exposed subjects | | | |
| 2 (S) | 67 | .6 | .6 |
| | 56 | .9 | 1.1 |
| | 61 | .8 | .7 |
| | 62 | 1.4 | 1.5 |
| | median | .9 | .9 |
| Ainslie & Herrnstein (1981) (C) | 1 | .8 | — |
| | 2 | 1.2 | — |
| | 3 | .6 | — |
| | 4 | 1.2 | — |
| | 5 | .7 | — |
| | 6 | .7 | — |
| | median | .8 | — |
| Green et al. (1981) (C) | 11 | .4 | — |
| | 12 | .3 | — |
| | 13 | .3 | — |
| | 14 | .3 | — |
| | median | .3 | — |

^aThe values of s_A/s_D were calculated either by the crossover point method using Equation 6 (C), or by the slopes method using Equations 4 and 5 (S).

^bThe following subjects never chose more small than large reinforcers in the trials procedure, and so their values of s_A/s_D calculated using the crossover point method are underestimates: 46, 291, and 5.

characterize relative sensitivity to different reinforcer continua, as in the present paper, can be successful even in procedures for which data are not well described by the matching law.

Equation 4 appears able to describe much of the research on choice in a self-control para-

digm within a single conceptual framework, including individual differences. It is also consistent with recent research on the matching law that has repeatedly shown that the exponent in Equation 1 is affected by the experimental procedure and by the history of the organism (see Baum, 1974a, 1974b, 1979; Davison, 1982; Davison & Hunter, 1979; de Villiers, 1977; Keller & Gollub, 1977, for discussions). There is no ideal exponent of 1.0 that the ideal matching law procedure will reveal, as has been previously implied (see de Villiers, 1977). Some procedures and continua yield one exponent and some yield another (see also Bertalanffy, 1968). Yet it is possible to predict what sorts of procedures will affect the exponents in what way. As Experiment 2 and Davison's (1982) research have shown, certain schedules of reinforcement do generate choice responding that is more extreme than the reinforcer distribution and consequently also generate relatively high exponents. In addition, pigeons with fading-procedure exposure tend to be more sensitive to reinforcer size than reinforcer delay when compared to pigeons without this exposure. The generalized matching law as applied to the self-control paradigm can be helpful in describing the effects of different procedures on subjects' choices between reinforcers of varying sizes and delays.

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