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HUMAN SELF-CONTROL AND THE DENSITY OF REINFORCEMENT

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Choice responding in adult humans on a discrete-trial button-pressing task was examined as a function of amount, delay, and overall density (points per unit time) of reinforcement. Reinforcement consisted of points that were exchangeable for money. In T 0 conditions, an impulsive response produced 4 points immediately and a self-control response produced 10 points after a delay of 15 s. In T 15 conditions, a constant delay of 15 s was added to both prereinforcer delays. Postreinforcer delays, which consisted of 15 s added to the end of each impulsive trial, equated trial durations regardless of choice, and was manipulated in both T 0 and T 15 conditions. In all conditions, choice was predicted directly from the relative reinforcement densities of the alternatives. Self-control was observed in all conditions except T 0 without postreinforcer delays, where the impulsive choices produced the higher reinforcement density. These results support previous studies showing that choice is a direct function of the relative reinforcement densities when conditioned (point) reinforcers are used. In contrast, where responding produces intrinsic (immediately consumable) reinforcers, immediacy of reinforcement appears to account for preference when density does not.

Key words: self-control, impulsiveness, density, amount of reinforcement, delay of reinforcement, button press, humans

Self-control is often defined as a choice of a large delayed reinforcer over a small immediate reinforcer. Impulsiveness is defined as the opposite choice (e.g., Logue, 1988; Rachlin & Green, 1972). Choice between two reinforcers will vary depending on relative amounts of and the relative delays to the receipt of the two possible reinforcers (e.g., Mazur, 1987). Behavioral accounts of self-control suggest that if both reinforcers are sufficiently delayed, then the larger, more delayed reinforcer will be chosen. However, as the delays decrease, a reversal of preference will occur and the smaller, more immediate reinforcer will be chosen. For example, Rachlin and Green (1972) found that when pigeons were offered a choice between immediate 2-s access to grain or 4-s access to grain delayed 4 s, they invariably chose the small reinforcer, corresponding to an impulsive choice. However, as the delays to both reinforcers were increased, the birds chose the larger reinforcer more often. These results illustrate a reversal of preference when equal intervals are added to unequal delays of reinforcement.

Experimental studies of self-control typically involve a number of choices and reinforcements during each session. This suggests that in addition to the effects that relative amounts and delays of reinforcement have on choice, the relative densities of reinforcement may also influence choice. Density is defined as the product of rate and amount of reinforcement per trial, that is, the amount of reinforcement divided by the total time between reinforcements (i.e., prereinforcer delay, reinforcement delivery period, postreinforcer delay and, possibly, the time spent to produce the reinforcer). In studies without postreinforcer delays, the choice over the long term (i.e., the experimental session) may be between a larger number of small immediate reinforcers and a smaller number of large delayed reinforcers (see Rachlin, 1989, chapter 7). This reduces to a choice between alternatives that have reinforcement density as a fundamental difference between them.

In self-control studies with humans, the qualitative nature of the reinforcer used may

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determine the quantitative property (density or immediacy) of reinforcement that controls preference. Specifically, experiments that have used immediately "consumable" (intrinsic) reinforcers that must be utilized as they occur and cannot be "saved up" until the end of the session have found that immediacy of reinforcement is a strong determinant of preference (Millar & Navarick, 1984; Navarick, 1982, 1986, 1987; Solnick, Kannenberg, Eckerman, & Waller, 1980). For example, strong impulsive responding occurred in studies using noise termination as the immediately consumable negative reinforcer (Navarick, 1982; Solnick et al., 1980). Indeed, in these studies the self-control alternative offered a higher relative reinforcement density, but density was sacrificed for immediate reinforcement. For example, in the Navarick (1982) study, 5 s of silence followed by 90 s of noise was preferred (median choice proportion = .94) over 75 s of noise followed by 20 s of silence (Navarick, 1982, p. 366, Table 1). When reinforcement density, as calculated in the previous paragraph, is determined for the alternatives, the alternative of immediate silence (the impulsive alternative) offered a reinforcement density of 0.053 and the alternative of delayed but extended silence (the self-control alternative) offered a density of 0.210. This indicates that subjects consistently chose the schedule with the lower reinforcement density.

In studies using intrinsic positive reinforcers (e.g., video-game playing: Millar & Navarick, 1984; picture viewing: Navarick, 1986, 1987), impulsive responding occurred under conditions without, or with minimal, postreinforcer delays (Millar & Navarick, 1984; Navarick, 1986). In such conditions the impulsive choice offered the highest relative reinforcement density. However, a degree of time urgency in choice was evident in that subjects were found to choose immediate reinforcement over delayed reinforcement when the amounts of reinforcement, intertrial intervals, and thus reinforcement densities were equal. It appears that impulsive responding, or at least a preference for immediacy, occurs when consumable reinforcers are used. Under such conditions relative density of reinforcement does not predict choice.

In contrast to studies employing intrinsic reinforcers, studies using conditioned reinforcers (i.e., points) typically have used free operant procedures in which choice responding was maintained on concurrent variable-interval (VI) schedules. These studies have all obtained self-controlled responding in adult subjects (e.g., Belke, Pierce, & Powell, 1989; Logue, King, Chavarro, & Volpe, 1990; Logue, Peña-Correal, Rodriguez, & Kabela, 1986; cf. Sonuga-Barke, Lea, & Webley, 1989). However, the basis for the self-control choices in the free operant experiments in which choice responses were made on concurrent VI schedules is less clear, because the VI schedule itself contributes to the interreinforcement interval and thus to reinforcement density. To facilitate comparison with the studies employing intrinsic reinforcers, the present experiment further investigated effects of reinforcement density under discrete-trials procedures. Reinforcement density was manipulated by varying the amount of reinforcement and the delays preceding and following reinforcement. Of particular interest was the preference reversal phenomenon mentioned earlier and the extent to which it might be predictable from the reinforcement densities associated with the schedules. Postreinforcer delays were manipulated between subjects, and prereinforcer delays were manipulated both between subjects and within subjects to determine whether responses to a specific set of prereinforcer delays were influenced by prior exposure to different prereinforcer delays.

METHOD

Subjects

The subjects were 34 introductory psychology students at the University of Georgia who participated in the experiment to fulfill part of the course requirement or to gain extra credit. Subjects signed up for sessions on an appointment sheet that offered times separated by 45 min.

Apparatus

The apparatus used was a Commodore® 128 computer interfaced with two push buttons. The buttons protruded from the top of a platform (10 cm by 25 cm). The left half of the platform was white and the right half was blue. One button was located at the center of each half of the platform.

The platform was positioned directly in front

of the computer monitor. The subject sat directly in front of the monitor. All sessions were conducted in a small white room (1.5 m by 2.1 m) that contained only a table, two chairs, the computer, the buttons, and the subject. Responses on the white button are referred to as "impulsive choices" and always produced the smaller, more immediate reinforcer relative to responses on the blue button, which are referred to as "self-control choices."

Procedure

Upon arriving at the experimental room, subjects were asked to remove their watches and read and sign an informed consent form. All subjects were then read the following instructions:

> This is an experiment on choice. The object is to score points. You score points by pressing buttons. Every point you earn is worth one cent. At the end of the session, you will be given the appropriate amount of money for the points you have acquired. It is up to you to figure out the best way to score points. Watch the computer screen during the experiment. The screen will say "press the white button," or "press the blue button," or it will say "choose a button and press it." Please make a choice when the computer asks you to do so. If you do not make a choice within three seconds of being asked, the session will end and you will not receive any money. The screen will also show how many points you have, tell you if you must wait before anything will happen, and provide you with any other information you will need for this experiment. You do not need to touch the computer keyboard or any wires in order to score points. The computer will tell you when the experiment is complete. I will be in the hall and will be able to see and hear you from there. I cannot answer any questions when the experiment is in progress, so if you have any please ask them now.

For each subject, the instructions were read once. If a subject had a question, the experimenter answered "yes," "no," or reread the appropriate section of the instructions. Next the experimenter said, "The experiment starts NOW," pressed a key to start the experiment, then went into the room across the hall. The experiment lasted between 5 and 40 min, depending on the condition to which the subject was assigned and the subject's responding.

Points served as reinforcers in all conditions. At the end of each session, 1 cent was exchanged for every point earned. Button presses during the computer-prompted choice period always earned 4 points for pressing the white button and 10 points for pressing the blue button. A previous study using free operant procedures (Flora & Pavlik, 1990), employing virtually the identical apparatus and the same subject population, yielded virtually identical response rates when conditions were identical for the two responses. This suggests that neither position nor color biases existed. Based on these observations, position and color preference were not controlled in the present study. If a button was not pressed within 3 s of the choice prompt, the session ended and the subject did not receive any money for points earned. During forced-choice trials, subjects had 5 s, not 3 s, to make a response. These limited-hold contingencies were added to avoid unprogrammed variability in reinforcement density and to ensure that subjects attended to stimuli on the screen. Conditions *T* 15 and *T* 0 represent between-subject comparisons, and conditions *T* 15/0 and *T* 0/15 represent within-subject comparisons (*T* refers to the time in seconds added to the standard prereinforcer delays). Each of the conditions was studied both with and without postreinforcer delays following impulsive choices. Table 1 summarizes the parameters of the study. The final column provides a measure of the overall density of reinforcement. Points per second were calculated by dividing the number of points for each alternative by the sum of the prereinforcer delay, reinforcer delivery period, and the postreinforcer delay.

Condition T *0/no postreinforcer delay.* In this, the simplest condition, subjects (2 males, 2 females) were presented with 36 trials, starting with four forced-choice trials (white, blue, white, blue) followed directly by 15 choice trials, two forced-choice trials (blue, white), and a final 15 choice trials. During choice trials, the monitor screen was lighted yellow with black alphanumeric characters. The prompt "Choose a button and press it" was printed directly above the subject's score. If the white button was pressed, the reinforcement period occurred immediately. During the reinforcement period the monitor screen turned white for 1 s, 4 points were added to the score, and a high-pitched tone sounded once, ending the trial. Then, immediately, the next trial started,

Table 1

Successive periods following choice response (durations in seconds).

Condition	Choice	Prereinforcer delay		Reinforcement period			Postreinforcer delay		Total duration	Points/s
		Duration	Color	Duration	Color	Points	Duration	Color		
No postreinforcer delay										
T 0	Impulsive	0	—	1	White	4	0	—	1	4.000
	Self-control	15	Gray	1	Blue	10	0	—	16	0.625
T 15	Impulsive	15	Gray	1	White	4	0	—	16	0.250
	Self-control	30	Gray	1	Blue	10	0	—	31	0.323
Postreinforcer delay										
T 0	Impulsive	0	—	1	White	4	15	White	16	0.250
	Self-control	15	Gray	1	Blue	10	0	—	16	0.625
T 15	Impulsive	15	Gray	1	White	4	15	White	31	0.129
	Self-control	30	Gray	1	Blue	10	0	—	31	0.323

signaled by the screen turning yellow again and prompting a choice (except when the next trial was a forced-choice trial). If the blue button was pressed, a 15-s delay occurred. During the delay period the monitor turned light gray and the word "wait" was printed to the immediate right of the subject's score. After the delay period the monitor screen turned blue for 1 s, 10 points were added to the score, and a high-pitched tone sounded three times during the 1-s period. Then, immediately, the next trial was prompted.

On forced-choice trials, the monitor was light green and prompted "Press the white button, only the white button will work now," or "Press the blue button, only the blue button will work now." Once the appropriate button was pressed, the programmed events were the same as when the button was pressed during a choice trial. If the inappropriate button was pressed, no programmed consequences occurred.

Condition T *15/no postreinforcer delay.* The same procedure as in *T* 0/no postreinforcer delay was used except that a constant time of 15 s was added to the prereinforcer delay for both impulsive and self-control choices. Thus, following an impulsive choice the screen turned gray for 15 s followed by reinforcement by 4 points, whereas after a self-control choice the screen turned gray for 30 s and the 10-point reinforcer was then delivered. Two male and 2 female subjects were used in this condition.

Condition T *0/postreinforcer delay.* The subjects (1 male, 3 females) experienced the same procedure as did the subjects in the *T* 0/no postreinforcer delay condition, except that reinforcements following impulsive choices were followed by a 15-s delay in which the screen remained white. This produced equal intertrial intervals (16 s) following both impulsive and self-control choices.

Condition T *15/postreinforcer delay.* The subjects (1 male, 4 females) experienced the same procedure as did the subjects in the *T* 15/no postreinforcer delay condition, except that reinforcements following impulsive choices were followed by a 15-s delay in which the screen remained white. This produced equal intertrial intervals (31 s) following both impulsive and self-control choices.

Conditions T *0/15 and* T *15/0.* In these conditions, each subject received both the *T* 0 and *T* 15 prereinforcer delays described above. In Condition *T* 0/15, the first four forced-choice trials and 15 choice trials were administered under the *T* 0 condition, and the last two forced-choice trials and final 15 choice trials were conducted under the *T* 15 condition. This sequence was reversed for Condition *T* 15/0. In both these within-subject conditions, some subjects were studied with postreinforcer delays and some without. Specifically, in Condition *T* 0/15, 1 female and 3 male subjects were studied without postreinforcer delays, and 1 male and 3 female subjects were studied with postreinforcer delays. In Condition *T* 15/0, 2 male and 3 female subjects were studied without postreinforcer delays, and 1 male and 3 females were studied with postreinforcer delays.

Table 2

Number of self-control choices for individual subjects in the between-subjects comparison (final 15 trials).

Condition	Subject	Self-control choices
No postreinforcer delay		
T 0	9	0
	10	0
	11	0
	12	5
T 15	13	15
	14	13
	15	15
	16	15
Postreinforcer delay		
T 0	26	12
	27	13
	28	9
	29	15
T 15	30	14
	31	15
	32	14
	33	15
	34	8

Table 3

Number of self-control choices for individual subjects in the within-subject comparison.

Subject	First 15 trials	Second 15 trials
No postreinforcer delay		
	T 0	*T* 15
17	11	14
18	2	11
19	8	14
20	9	8
	T 15	*T* 0
21	7	8
22	15	1
23	12	5
24	13	15
25	8	1
Postreinforcer delay		
	T 0	*T* 15
35	2	13
36	9	15
37	12	14
38	13	8
	T 15	*T* 0
39	10	14
40	10	13
41	14	13
42	13	15

RESULTS

No subjects were eliminated because of failure to respond during the limited-hold choice periods. The data analyzed were the number of self-control choices made by each subject. Table 2 presents individual-subject data for the between-subjects comparison; Table 3 presents data for the within-subject comparison.

No Postreinforcer Delays

Fewer self-control choices (i.e., greater impulsivity) occurred in the *T* 0 conditions relative to the *T* 15 conditions in both between- and within-subject comparisons. Direction of choice was directly related to the relative reinforcement densities (Table 1) of the two schedules. Specifically, for all 30 choice trials, in the between-subjects comparison, subjects in Condition *T* 0 made a mean of 7.5 self-control choices, and the subjects in Condition *T* 15 made a mean of 25.25 self-control choices, $F(1, 6) = 21.512$, $p < .01$. During the final 15 choice trials, subjects in Condition *T* 0 made a mean of only 1.25 self-control choices, and subjects in Condition *T* 15 made a mean of 14.5 self-control choices, $F(1, 6) = 96.9$, $p < .0001$ (Figure 1, left).

The same pattern of results was observed in the within-subject comparison (i.e., Conditions *T* 0/15 and *T* 15/0) as that observed in the between-subjects comparison (Figure 2, left). However, preferences at different values of *T* (0 or 15) for the within-subject comparisons were less extreme than in the between-subjects comparison. When these data are collapsed across sequences (0/15 and 15/0), subjects made a mean of 6.5 self-control choices at *T* 0 and a mean of 11.875 self-control choices at *T* 15, $F(1, 7) = 8.344$, $p < .05$. As in the between-subjects comparisons, the within-subject comparisons revealed that mean choice was directly related to the relative reinforcement densities.

When *T* was changed from 0 to 15, the subjects' responses (except Subject 20) became more self-controlled (Figure 2, Tables 2 and 3). Similarly, when *T* was changed from 15 to 0, subjects' behavior (except Subject 24) became more impulsive. Subject 21's data were not included in the within-subject ANOVA, or in Figure 2, because his behavior was clearly

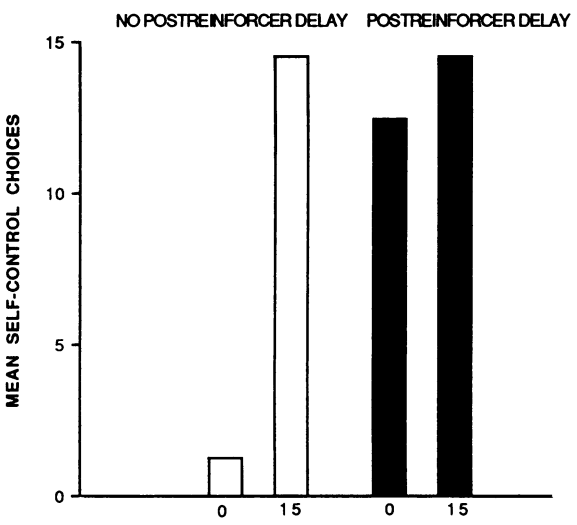

Fig. 1. Mean self-control choices during the final 15 choice trials as a function of prereinforcer delay for the between-subjects comparisons, with and without postreinforcer delays.

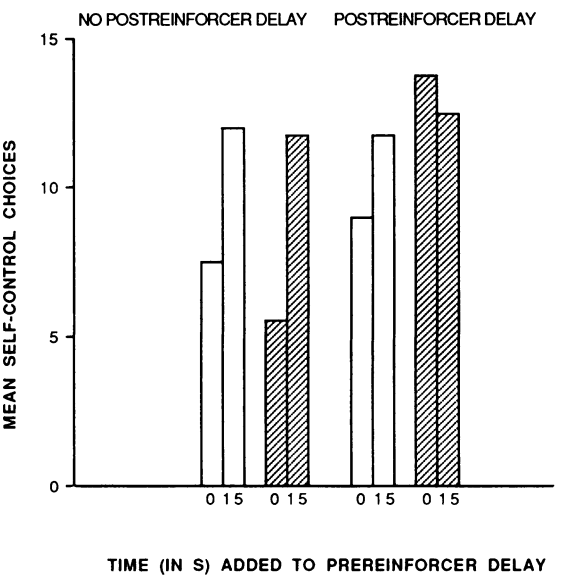

Fig. 2. Mean self-control choices as a function of prereinforcer delays for within-subject comparisons, with and without postreinforcer delays. The left-hand pair of bars in each postreinforcer delay condition indicate that subjects received the T 0 condition before the T 15 condition; the right-hand pair of bars in each postreinforcer delay condition indicate that subjects received the T 15 condition before the T 0 condition.

an instruction response as opposed to being contingency driven (see Baron & Galizio, 1983, for a review of instruction-controlled responding). That is, this subject's behavior appeared to be controlled by the four instructional prompts during the first forced-choice trials: "Press the white button.... Press the blue button.... Press the white button.... Press the blue button." This instructed switching behavior was carried over to the choice trials and was maintained throughout the experiment.

Postreinforcer Delays Included

With postreinforcer delays included, all subjects in all conditions made a majority of self-control choices (Table 2). There were no statistically significant differences between T 0 and T 15 in either the between-subjects, $F(1, 6) = 3.075$, or within-subject, $F(1, 7) = 0.148$, comparisons. Most subjects made a majority of self-control choices. Two exceptions, Subjects 34 and 35, both made 50% self-control choices. Subject 34's behavior, like that of Subject 21, appeared to be instruction controlled, alternating impulsive and self-control choices, and was not included in Figure 2 or the statistical analyses. (Data for Subject 35 were included.)

In the between-subjects comparison, based on the final 15 trials, subjects in the T 0 condition made a mean of 12.25 self-control choices, whereas subjects in the T 15 condition made a mean of 14.5 self-control choices. In the within-subject comparison, collapsing across sequences, subjects made a mean of 11.375 self-control choices when T was 0 and a mean of 12.125 self-control choices when T was 15. Thus, regardless of the value of T, when a postreinforcer delay was added to impulsive choice trials, subjects chose the large delayed reinforcer on the majority of trials in both the between- and within-subject conditions. With postreinforcer delays included, the self-control choice provided the higher reinforcement density in both T 0 and T 15 conditions (Table 1). Therefore, as in the conditions without postreinforcer delays, choice was directly related to the reinforcement densities of the two schedules.

The particular sequence in which the two prereinforcer delays were experienced (0/15 or 15/0) appeared to have no consistent effect on responding when there were no postreinforcer delays (Figure 2). However, with post-

reinforcer delays, more self-control choices were made during the final 15 choice trials in both sequences. This resulted, counterintuitively, in even more self-control choices (on average) in the T 0 condition than in the T 15 condition in the 15/0 sequence, $t(6) = 1.76$, $p > .05$, and may suggest that prior experiences can operate to strengthen maximization tendencies. However, this result was not statistically significant, and such a possibility remains tentative.

In the between-subjects comparisons shown in Figure 1, the mean number of self-control choices during the final 15 choice trials for the T 0 condition was 1.25 when there was no postreinforcer delay, but was 12.25 when there was a postreinforcer delay. This difference in self-control was statistically significant, $F(1, 6) = 38.7$. In contrast, the mean number of self-control responses during the final 15 trials in the T 15 conditions, both with and without postreinforcer delays following impulsive choices, was 14.5. Clearly, impulsive behavior occurred only when there were neither prereinforcer nor postreinforcer delays and, therefore, only when the overall density of reinforcement was greater for the impulsive choice than for the self-control choice.

DISCUSSION

The principal finding of the present study was that impulsive responding was produced in adult humans in a discrete-trial task with conditioned reinforcers (points), but only under conditions in which the overall density of reinforcement (points per second) was greater for impulsive responding than for self-control responding. The effect of varying prereinforcer delays is shown most clearly in the left portion of Figure 2. Here, without postreinforcer delays, within-subject increases or decreases in prereinforcer delays resulted in substantial shifts from impulsive to self-control responding, or vice versa. However, when postreinforcer delays were used, no shift in responding occurred, presumably because the self-control alternative continued to offer the higher reinforcement density.

The finding that density of reinforcement controlled choice in this study is consistent with the results of Experiment 1 of Logue et al. (1986), which employed a discrete-trials procedure with postreinforcer delays included. This resulted in a greater reinforcer density for self-control choices, and consistent self-control was observed. Together with the findings of free operant experiments, the results from the discrete-trials procedures suggest that various equations that have been offered to describe choice behavior (e.g., Herrnstein, 1970; Logue, 1988; Mazur, 1987; Rachlin, 1989; Williams, 1988) should include a term describing the relative overall densities of reinforcement independent of relative amounts and delays of individual reinforcers. In fact, Rachlin (1989) and Williams (1988) do suggest equations that include such a term.

Finally, the role of relative density of reinforcement in determining choice responding in humans may be of primary importance only when responses produce conditioned positive reinforcers that can be accumulated over time, as in the present study. In cases in which responding produces immediately consumable positive reinforcers, overall density appears to play a lesser role. With both video game playing and picture viewing as reinforcers, when reinforcement density was equal for the two alternatives a preference for immediacy was observed (Millar & Navarick, 1984; Navarick, 1986; cf. Navarick, 1987). In cases in which responding is negatively reinforced, immediacy of reinforcement has been observed to play a greater role than overall density. In these studies, subjects chose immediate but brief escape over delayed but extended escape; this preference reduced the total amount of escape or reinforcement density (e.g., Navarick, 1982; Solnick et al., 1980). Of course, this suggests that the particular effects of different variables (including relative reinforcement density) on choice behavior may well depend upon the particular type of reinforcer used and that no simple single mathematical equation for choice behavior may be feasible.

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