

*DETERMINANTS OF PIGEONS' CHOICES IN TOKEN-BASED SELF-CONTROL PROCEDURES*

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Four pigeons were exposed to a token-based self-control procedure with stimulus lights serving as token reinforcers. Smaller-reinforcer choices produced one token immediately; larger-reinforcer choices produced three tokens following a delay. Each token could be exchanged for 2-s access to food during a signaled exchange period each trial. The main variables of interest were the exchange delays (delays from the choice to the exchange stimulus) and the food delays (also timed from the choice), which were varied separately and together across blocks of sessions. When exchange delays and food delays were shorter following smaller-reinforcer choices, strong preference for the smaller reinforcer was observed. When exchange delays and food delays were equal for both options, strong preference for the larger reinforcer was observed. When food delays were equal for both options but exchange delays were shorter for smaller-reinforcer choices, preference for the larger reinforcer generally was less extreme than under conditions in which both exchange and food delays were equal. When exchange delays were equal for both options but food delays were shorter for smaller-reinforcer choices, preference for the smaller reinforcer generally was less extreme than under conditions in which both exchange and food delays favored smaller-reinforcer choices. On the whole, the results were consistent with prior research on token-based self-control procedures in showing that choices are governed by reinforcer immediacy when exchange and food delays are unequal and by reinforcer amount when exchange and food delays are equal. Further, by decoupling the exchange delays from food delays, the results tentatively support a role for the exchange stimulus as a conditioned reinforcer.

*Key words:* choice, self-control, token reinforcement schedules, key peck, pigeons

In a procedure that has gained popularity as a laboratory model of self-control, subjects are given repeated choices between a smaller reinforcer available immediately and a larger reinforcer available after a delay. With adult human subjects, the reinforcers typically consist of points exchangeable for some other reinforcer (usually money) at some later time. Under these conditions, human subjects show a strong preference for the larger but delayed number of points (Flora & Pavlik, 1992; Logue, King, Chavarro, & Volpe, 1990; Logue, Peña-Correal, Rodriguez, & Kabela, 1986). Such performance has been taken as evidence of self-control, as contrasted with impulsiveness, defined as preference for the smaller but more immediate reinforcer (see review by Logue, 1988).

Self-control and impulsiveness are usually

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thought to reflect differing degrees of sensitivity to reinforcer amount and reinforcer delay, respectively. The typical finding is that humans' choices appear to be governed to a greater extent by reinforcer amount than by reinforcer delay. This relative insensitivity to reinforcer delay in humans contrasts sharply with the delay sensitivity normally seen in nonhuman subjects (Logue, 1988), posing a potentially troubling discontinuity between human and nonhuman behavior. As Logue et al. (1986) put it, "... adult humans, unlike pigeons, are sensitive to events as integrated over whole sessions and tend to maximize total reinforcement over whole sessions" (p. 172).

This interpretation assumes that points are the reinforcers with respect to which self-control and impulsiveness are defined. Recent research, however, has called this interpretation into question. If money rather than points is viewed as the relevant reinforcer, then the procedure can be reconceptualized as a higher-order schedule of token reinforcement. A token reinforcement schedule consists of three component schedules arranged successively: (a) a token schedule—the schedule according to which the tokens (in this case,

points) are produced, (b) an exchange schedule—the schedule according to which opportunities for exchanging the points for other reinforcers are made available, and (c) a terminal reinforcer schedule—the schedule according to which exchange responses produce the terminal reinforcer (in this case, money).

Viewed within the context of a token reinforcement schedule, the delays to points (the focus of traditional analyses) constitute only part of the overall delay to monetary reinforcers. The other (and perhaps more critical) delay is that between choices and opportunities to exchange points for monetary reinforcers (the exchange delay). Such exchange delays normally do not vary in experiments with humans. This is because (a) exchange opportunities are usually made available following the last choice trial of a session, and (b) choice trials are usually scheduled to occur at regular intervals. Thus, while monetary reinforcer *amount* depends directly on choice patterns, monetary reinforcer *delay* does not: the delay to the exchange period (and to the monetary reinforcers obtainable therein) is the same regardless of the choices on individual trials. When viewed in this way, preference for a larger number of points each trial (normally taken as evidence of self-control) can be viewed as sensitivity to reinforcer amount (more vs. less money) with delays to those reinforcers held constant.

This interpretation is consistent with research in which token delays have been pitted directly against exchange delays. Hyten, Madden, and Field (1994), for example, gave adult humans choices between a small number of points delivered immediately and a larger number of points delivered after a delay. Points were later exchangeable for money. When delays to exchange periods were equal for either alternative, as they are in the typical procedural arrangement, strong preference for the larger reinforcer prevailed. Preference for most subjects reversed to favoring the smaller reinforcer when delays to the exchange period were made longer for the larger reinforcer while holding constant the delay to the exchange period for the smaller reinforcer. For these subjects, then, self-control choices depended not on delays to tokens (points) but rather on the delays to

periods during which those tokens could be exchanged for other reinforcers (money).

In a similar vein, Jackson and Hackenberg (1996) examined pigeons' choices in a self-control arrangement with token-like reinforcers. The goal was to arrange conditions with pigeons that more closely approximated those typically used in self-control procedures with human subjects. Choices resulted in the illumination (delivery) of either one or three stimulus lights as a form of token reinforcement. Each illuminated light, or token, could be exchanged for 2-s access to food during scheduled exchange periods. In a series of four experiments, a range of conditions involving various delays to tokens and to exchange periods was examined. In the critical self-control conditions, pigeons chose between one token (smaller reinforcer) delivered immediately and three tokens (larger reinforcer) delivered after a 6-s delay. Preference for the smaller reinforcer was observed consistently when delays to exchange periods were shorter following smaller-reinforcer choices, but reversed when exchange delays were equal. This pattern of self-control was found for most subjects even under conditions with a single exchange period at the end of a 10-trial session—a condition most closely analogous to human experiments in which points are exchangeable for other reinforcers at the end of a session. Thus, as with Hyten et al.'s (1994) humans' choices, pigeons' choices in a self-control context depended on the delays to the exchange period rather than on the delays to tokens.

The present study was designed to explore further the determinants of pigeons' choices in token-based self-control procedures. Pigeons chose between a smaller reinforcer (one token exchangeable for 2-s food access) and a larger reinforcer (three tokens exchangeable for 6-s food access). The delays between choices and different stimulus events (tokens, exchange stimuli, and food) in the token-reinforcement schedule were varied separately and together across conditions. In all conditions, delays to token deliveries were shorter following smaller-reinforcer (one-token) choices than larger-reinforcer (three-token) choices. In some conditions, the exchange period and subsequent food delivery was scheduled immediately after token delivery, such that the delays to all three potential

sources of reinforcement (tokens, exchanges, and food) favored smaller-reinforcer choices. In other conditions, the exchange period occurred after a fixed delay timed from the choice. In these conditions, smaller-reinforcer choices continued to produce tokens more quickly but had no effect on delays to the exchange period or to food. In still other conditions, smaller-reinforcer choices produced shorter delays to tokens and to exchange periods but not to food.

Because reinforcer amount favored larger-reinforcer choices under all conditions, the experiment permitted an assessment of the trade-offs between reinforcer amount and the various reinforcer delays in a token-based self-control procedure. If choices are insensitive to all three delays (token delay, exchange delay, and food delay), preference for the larger reinforcer would be expected under all conditions. If choices are sensitive to token delays, then preference for the smaller reinforcer would be expected under all conditions. If choices are sensitive to exchange and/or food delays, then preference would be expected for the smaller reinforcer under conditions with shorter delays to these reinforcers, and for the larger reinforcer with equal delays to these reinforcers. Together, the results permit an evaluation of the respective contributions of token, exchange, and food delays in token-based self-control procedures.

## METHOD

### *Subjects*

Four White Carneau pigeons (designated 710, 743, 777, and 866) with prior experience on token-based choice procedures served as subjects. The pigeons were maintained at approximately 80% of their free-feeding weights. They were housed individually and had continuous access to water and grit in a temperature and humidity-controlled colony room (lights on from 7:30 a.m. to 11:00 p.m.).

### *Apparatus*

An operant conditioning chamber, with a work area measuring 360 mm high by 360 mm wide by 540 mm long, served as the experimental space. Three horizontally-aligned plastic response keys (25 mm) were mounted 90 mm apart and 93 mm from the outside

edges of the intelligence panel. A houselight, mounted 80 mm above the center key, provided diffuse illumination. The intelligence panel was modified to include a row of 30 red light-emitting diodes (LEDs) mounted horizontally 60 mm above the response keys and 20 mm below the houselight. The far left and far right LEDs were situated 25 mm from the edges of the panel. Lamps mounted behind the side keys could be illuminated green or yellow, and lamps mounted behind the center key could be illuminated red or white. A rectangular opening (60 mm wide by 54 mm high), situated 156 mm below the left key and 97 mm from the left edge of the panel, provided access to a raised food hopper. A photobeam mounted in the hopper enclosure permitted precise timing of hopper access. The chamber was enclosed within a sound-attenuating box. Ambient white noise in the room and an exhaust fan within the shell also helped mask extraneous noise. A mechanical stepping switch, sitting on the top outside of the box, controlled the presentation and removal of LEDs. A computer and Med Associates interface and software, located in a separate room, controlled operation of the stepping switch and all other events in the chamber.

### *Procedure*

The subjects had previous experience in token-based procedures, so no training was necessary. Sessions consisted of two blocks of 10 trials each. The first 10 trials were forced trials with equal numbers of smaller-reinforcer and larger-reinforcer choices. The final 10 trials were choice trials with both alternatives simultaneously available. Trials of either type began with the center key illuminated white. A single peck on this key turned it off and produced either one or both side keys, depending on whether it was a forced trial or a choice trial. A single peck on the side key associated with the smaller reinforcer turned off both choice keys and the houselights and illuminated the far left LED (hereafter, token) immediately. A single peck on the side key associated with the larger reinforcer turned off both choice keys and the houselights and produced the far left three tokens in succession after a delay of  $x$  s, the value of which was determined individually for each subject (see below). Tokens remained lit until

the exchange period at the end of each trial, signaled by a red center key. A single peck on this red center (exchange) key turned off one token and produced 2-s access to food (timed from head in hopper). The second and third food deliveries in a larger-reinforcer exchange period also required only a single response. The exchange period ended when all tokens earned that trial had been exchanged for food (all LEDs extinguished). The intertrial interval (ITI) was adjusted to maintain a fixed trial spacing of 60 s (or 90 s for the 50-s food delay conditions, see below). The color and position assignments were counterbalanced across subjects: 710 (larger = left, yellow), 743 (larger = right, green), 777 (larger = right, yellow), 866 (larger = right, green).

The value of  $x$ , the token delay on trials with a larger-reinforcer choice, was determined empirically for each subject, based on prior data (not shown here) collected with an adjusting-delay procedure (Mazur, 1987). On this type of procedure, the delay to the larger (6-s) reinforcer was varied across blocks of trials until a delay value was found at which it was selected in equal proportion to a smaller (2-s) reinforcer. This delay value, termed an indifference point, was multiplied by 1.5 and rounded up to the nearest integer. For example, the mean indifference point identified for Subject 710 was 7 s, so the pretoken delay used for this subject was 11 s. This 50% increase was selected so as to place the programmed delays outside the range of delays experienced in the sessions from which the indifference points were computed. The delay values for Pigeons 866, 743, and 777 were 10 s, 14 s, and 17 s, respectively. These delay values were held constant for each pigeon across the various conditions of the experiment.

The main variables of interest were the delays to the exchange stimulus (red center key) and the delays to food. The delays to these events were either equal for both choices or were shorter for smaller-reinforcer choices, yielding the following four condition types: (a) Unequal Exchange Delay, Unequal Food Delay (UED/UFD), (b) Equal Exchange Delay, Equal Food Delay (EED/EFD), (c) Unequal Exchange Delay, Equal Food Delay (UED/EFD), and (d) Equal Exchange Delay, Unequal Food Delay (EED/UFD).

The experiment was divided into two parts. Part 1 involved condition Types 1 and 2 only; Part 2 involved all four condition types. The differences between the four conditions are illustrated in Figure 1. The top panels depict the trial structure for the two conditions used in Part 1. In both conditions, tokens followed smaller-reinforcer choices immediately and larger-reinforcer choices after an individually-determined delay, as described above. In UED/UFD conditions, both the exchange delays and food delays were shorter following smaller-reinforcer choices, the exchange stimulus was presented just after token delivery, and food was available for responses on the exchange key. Each exchange response produced food, followed by the ITI. In EED/EFD conditions, the exchange delays and food delays were equal for both alternatives, and the exchange stimulus was presented after a fixed delay from either choice equal to  $x + 0.7$  s (the pretoken delay plus the time required to deliver three tokens on the larger-reinforcer alternative). Food was available for each response on the exchange key.

The bottom panels of Figure 1 depict the trial structures for the conditions comprising Part 2 of the experiment. Unlike Part 1, in which each exchange response produced food, exchange responses in some conditions of Part 2 produced food according to a tandem fixed-time 30 fixed-ratio 1 (TAND FT FR 1) schedule (i.e., following the first exchange response after the FT schedule elapsed, 30 s from the choice response). This was done to hold the food delays constant at 30 s across different condition types while preserving the dependency between responses and food.

In the UED/UFD condition, the consequences for smaller-reinforcer choices were as in the analogous Part 1 condition: immediate presentation of token and exchange stimulus, in the presence of which a single response produced food. Selecting the larger-reinforcer option produced the exchange stimulus immediately after the delayed token presentation, as in Part 1. In the presence of the exchange stimulus, however, the tandem FT FR 1 schedule was in effect, such that food was available for the first response after the FT had elapsed. Because the specific value of the token and exchange delays varied across subjects, the portion of the FT in the presence of the exchange stimulus was adjusted

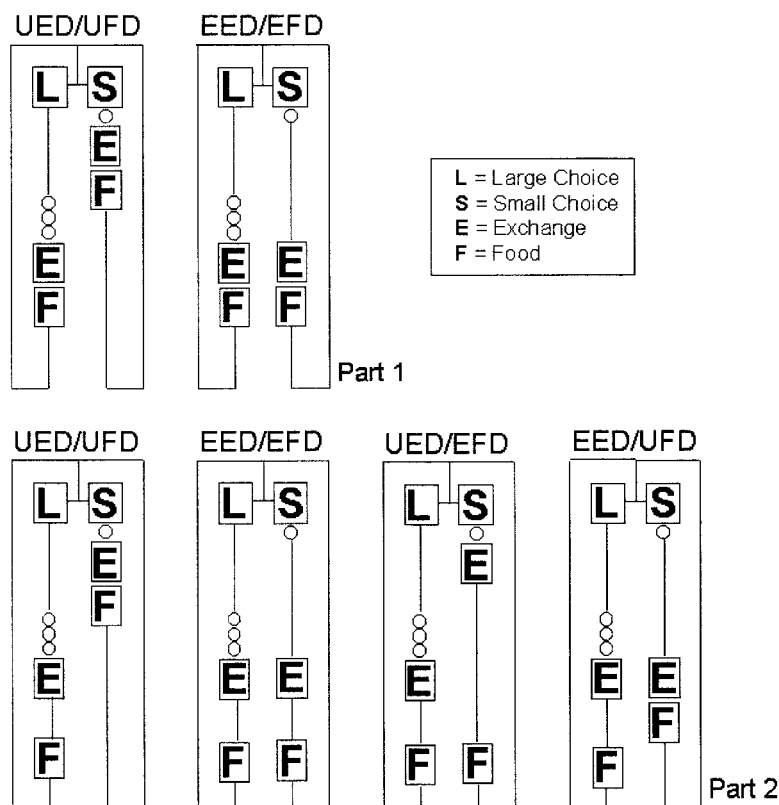


Fig. 1. Procedural schematics depicting the four main condition types used in the experiment. See text for details.

to maintain a 30-s delay to food, timed from the choice. In the EED/EFD condition, the token and exchange delays following smaller-reinforcer and larger-reinforcer choices were the same as analogous conditions in Part 1. In the presence of the exchange stimulus, the tandem FT FR 1 schedule was in effect. Smaller-reinforcer and larger-reinforcer choices thus produced equal delays to the exchange stimulus ( $x + 0.7$  s) and to food (30 s). In the UED/EFD condition, the food delays were equal for both alternatives but the exchange delays were shorter following smaller-reinforcer choices. The exchange stimulus was presented immediately after token presentation, and exchange responses produced food when the FT component of the tandem schedule had elapsed, 30 s from either choice. In the EED/UFD condition, the exchange delays were equal for both alternatives but the food delays were shorter following smaller-reinforcer choices. This was accomplished by arranging differential food

delays in the presence of the exchange stimulus: FR 1 for smaller-reinforcer choices and tandem FT FR 1 for larger-reinforcer choices.

Conditions lasted for a minimum of 15 sessions and until the number of larger-reinforcer choices showed no systematic upward or downward trends for five consecutive sessions on visual inspection. Between the completion of Part 1 and Part 2, the pigeons received several months of exposure to a range of conditions in which the exchange ratio was manipulated. Data from these conditions are not reported here. In Part 2, three pigeons (710, 743, and 777) were exposed to several additional conditions with tandem FT 50 FR 1 schedules rather than FT 30 FR 1 schedules. Trials began every 90 s instead of every 60 s in these conditions. Table 1 lists the sequence of conditions, the exchange and food delays following smaller-reinforcer and larger-reinforcer choices under each condition, and the number of sessions per condition for each pigeon.

Table 1

Sequence of conditions, number of sessions per condition, and programmed exchange delays (ED) and food delays (FD) for smaller-reinforcer (S) and larger-reinforcer (L) choices. Note: UED = Unequal Exchange Delay, EED = Equal Exchange Delay, UFD = Unequal Food Delay, and EFD = Equal Food Delay. "R" designates conditions with a key reversal.

Pigeon	Condition	ED-S (s)	ED-L (s)	FD-s (s)	FD-L (s)	Sessions	
866	Part 1						
	UED/UFD	0.3	10.7	0.3	10.7	45	
	EED/EFD	10.7	10.7	10.7	10.7	28	
	UED/UFD	0.3	10.7	0.3	10.7	32	
	EED/EFD	10.7	10.7	10.7	10.7	30	
	Part 2						
	EED/EFD	10.7	10.7	30	30	21	
	UED/UFD	0.3	10.7	0.3	30	29	
	UED/EFD	0.3	10.7	30	30	30	
	EED/UFD	10.7	10.7	10.7	30	29	
	UED/EFD	0.3	10.7	30	30	25	
	EED/UFD	10.7	10.7	10.7	30	26	
	EED/EFD	10.7	10.7	30	30	25	
	UED/UFD	0.3	10.7	0.3	30	28	
	743	Part 1					
		UED/UFD	0.3	14.7	0.3	14.7	22
EED/EFD		14.7	14.7	14.7	14.7	23	
UED/UFD		0.3	14.7	0.3	14.7	37	
EED/EFD		14.7	14.7	14.7	14.7	37	
Part 2							
EED/EFD		14.7	14.7	30	30	20	
EED/UFD		14.7	14.7	14.7	30	36	
EED/UFD		14.7	14.7	14.7	50	22	
UED/EFD		0.3	14.7	50	50	34	
UED/EFD-R		0.3	14.7	50	50	17	
EED/EFD		14.7	14.7	50	50	31	
777	Part 1						
	UED/UFD	0.3	17.7	0.3	17.7	59	
	EED/EFD	17.7	17.7	17.7	17.7	22	
	UED/UFD	0.3	17.7	0.3	17.7	26	
	EED/EFD	17.7	17.7	17.7	17.7	24	
	Part 2						
	EED/EFD	17.7	17.7	30	30	22	
	EED/UFD	17.7	17.7	17.7	30	54	
	EED/UFD	17.7	17.7	17.7	50	25	
	UED/EFD	0.3	17.7	50	50	20	
	UED/EFD-R	0.3	17.7	50	50	18	
	EED/EFD	17.7	17.7	50	50	37	
710	Part 1						
	UED/UFD	0.3	11.7	0.3	11.7	46	
	EED/EFD	11.7	11.7	11.7	11.7	21	
	UED/UFD	0.3	11.7	0.3	11.7	43	
	EED/EFD	11.7	11.7	11.7	11.7	29	
	Part 2						
	EED/EFD	11.7	11.7	30	30	24	
	EED/UFD	11.7	11.7	11.7	30	31	
	UED/EFD	0.3	11.7	30	30	44	
	EED/UFD	11.7	11.7	11.7	30	35	
	EED/UFD	11.7	11.7	11.7	50	68	
	UED/EFD	0.3	11.7	50	50	29	
	UED/EFD-R	0.3	11.7	50	50	38	
	UED/EFD	0.3	11.7	50	50	29	
UED/EFD	0.3	11.7	30	30	22		
EED/UFD	11.7	11.7	11.7	30	35		
EED/UFD	11.7	11.7	11.7	50	17		

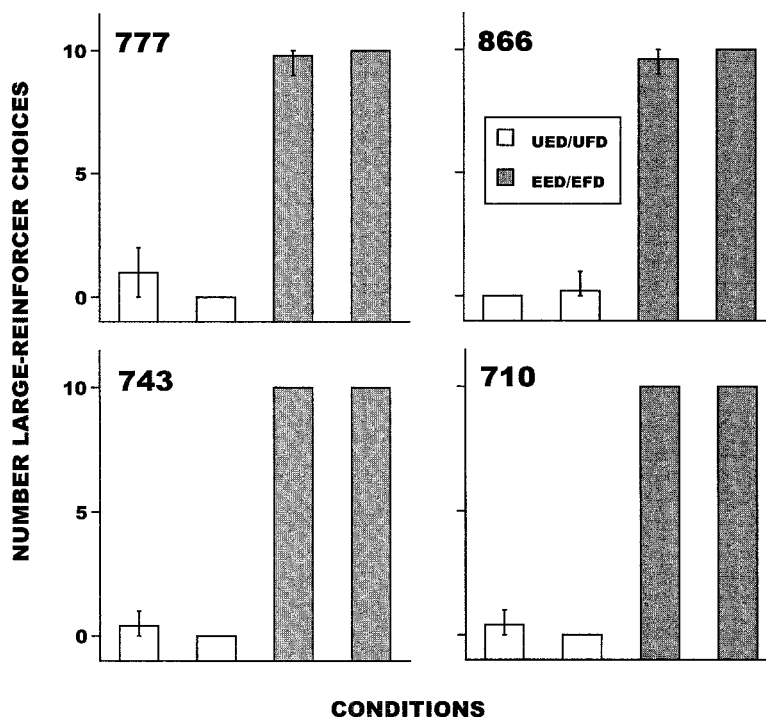


Fig. 2. Mean number of larger-reinforcer choices per session over the last five sessions of each condition in Part 1. Data from EED/EFD and UED/UFD conditions are denoted by filled and unfilled bars, respectively. Vertical lines show the range of values used to determine the mean.

## RESULTS

Figure 2 shows the number of larger-reinforcer choices for each pigeon across the four conditions comprising Part 1 of the experiment (two exposures each of Condition Types 1 and 2: UED/UFD and EED/EFD). The bars are means taken from the final five sessions in each condition and the error bars are ranges. Because a session consisted of 10 choice trials, values above five reflect preference for the larger reinforcer, whereas values below five reflect preference for the smaller reinforcer. Under UED/UFD conditions (open bars), in which both exchange delays and food delays were shorter on trials with small-reinforcer choices, all pigeons strongly preferred the smaller reinforcer (mean choice proportion of .02 across subjects). Under EED/EFD conditions (filled bars), in which exchange delays and food delays were equal for both alternatives, all pigeons strongly preferred the larger reinforcer (mean choice proportion of .99 across subjects).

Figures 3 and 4 show the number of larger-reinforcer choices for each pigeon across

conditions in Part 2 of the experiment. To facilitate comparisons, conditions with unequal and equal food delays are shown separately. Figure 3 shows conditions with unequal food delays. When exchange and food delays were shorter on trials with smaller-reinforcer choices (UED/UFD, open bars), strong preference for the smaller reinforcer was seen. Although these conditions were only conducted with Pigeons 866 and 710 in Part 2, they are consistent with the strong preference for the smaller reinforcer seen in Part 1 (eight of eight conditions, across subjects). The relevant comparison condition here is to EED/UFD (filled bars), in which exchange delays were equal but food delays were shorter on trials with smaller-reinforcer choices. Unlike the strong preference for the smaller reinforcer seen in UED/UFD conditions, the smaller reinforcer was preferred in only six of 10 conditions across subjects, including only two of six conditions with 30 s delays to food.

The results of this comparison suggest sensitivity to exchange delays with unequal food

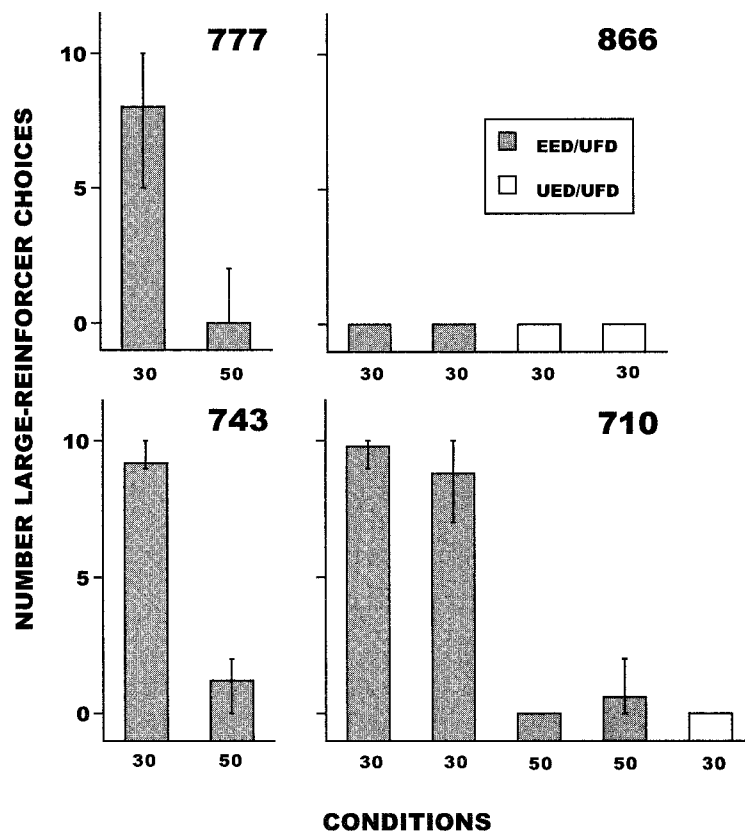


Fig. 3. Mean number of larger-reinforcer choices per session over the last five sessions of conditions in Part 2 with unequal food delays. Data from EED/UFD and UED/UFD conditions are denoted by filled and unfilled bars, respectively. Vertical lines show the range of values used to determine the mean. The number below each bar represents the value (s) of the FT component of the tandem FT FR 1 schedule.

delays, but there were individual differences in such sensitivity worth noting. Pigeon 866's choices showed little sensitivity to exchange delays: strong preference for the smaller reinforcer was seen under both conditions with unequal food delays, irrespective of exchange delays. For the other 3 pigeons, sensitivity to the exchange delay was first seen in the EED/UFD 30 condition, in which the larger reinforcer generally was preferred despite shorter food delays on trials with smaller-reinforcer choices. Preference reversed in favor of the smaller reinforcer when the food delay on trials with larger-reinforcer choices was increased to 50 s (EED/UFD 50) for all 3 pigeons, and reversed back in favor of the large for the 1 pigeon (710) reexposed to EED/UFD 30 procedure.

Figure 4 shows conditions with equal food delays. When exchange and food delays were

equal for both alternatives (EED/EFD, filled bars), the larger reinforcer was generally preferred (five of six conditions, across subjects), which is consistent with Part 1 results (eight of eight conditions, across subjects). The comparison condition for assessing the contributions of the exchange schedule is UED/EFD (open bars), in which food delays were the same but the exchange delay was shorter for smaller-reinforcer choices. Unlike the strong preference for the larger-reinforcer delay with equal exchange delays, the larger-reinforcer was preferred in only 5 of 11 conditions across subjects, including only one of the seven Part-2 conditions with 50-s delays to food.

As with the comparisons with unequal food delays, Pigeon 866's choices again revealed little sensitivity to exchange delays; this subject strongly preferred the larger reinforcer



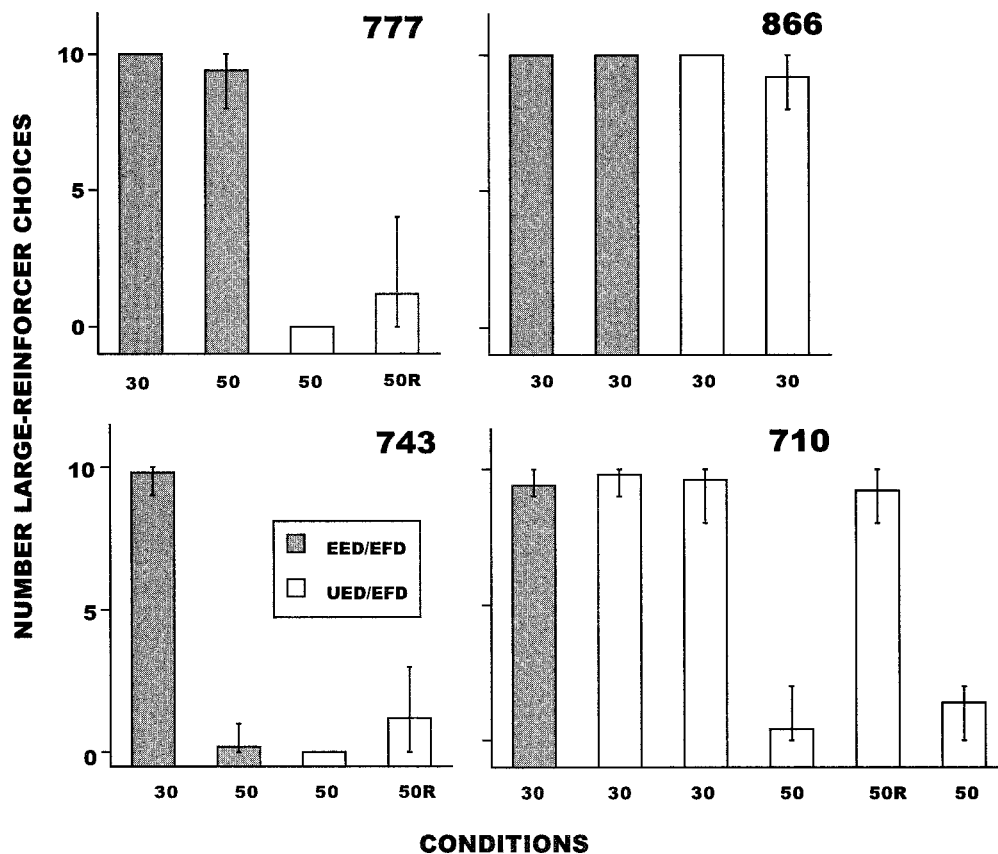


Fig. 4. Mean number of larger-reinforcer choices per session over the last five sessions of conditions in Part 2 with equal food delays. Data from EED/efd and UED/efd conditions are denoted by filled and unfilled bars, respectively. Vertical lines show the range of values used to determine the mean. The number below each bar represents the value (s) of the FT component of the tandem FT FR 1 schedule; "R" designates conditions with a key reversal. Conditions with 50-s food delays are noted by (50), and key reversals by "R."

under both conditions with equal food delays without regard to the associated exchange delays. For the other 3 pigeons, there were clear differences in preference between UED/efd and EED/efd conditions, especially at the longer food delays where it was seen in all 3 subjects (and six of seven conditions) studied on this procedure. Although a key reversal condition to assess bias resulted in a preference reversal for Pigeon 710, Pigeons 743 and 777 continued to prefer the smaller reinforcer. When the exchange delays were made equal while also holding food delays equal in the subsequent condition (EED/efd 50), preference reversed in favor of the larger reinforcer for 777 but not for 743, suggesting the possibility of key bias.

In conditions with the tandem FT FR 1 schedule in the presence of the exchange

stimulus, the obtained food delays could exceed the programmed delays. Unfortunately, obtained delays were not collected. Informal observations, however, indicated that response rates were sufficiently high that the differences between programmed and obtained delays were minimal.

### DISCUSSION

The present study was designed to shed further light on the determinants of choice in token-based self-control procedures. The findings replicate and extend the results of Jackson and Hackenberg (1996) showing that the delays to food and food-correlated (exchange) stimuli are more critical determinants of pigeons' choices than are delays to token delivery. In particular, the results show

that choices are governed by reinforcer immediacy (impulsiveness) when delays to exchange stimuli and food are unequal and by reinforcer amount (self-control) when delays to exchange stimuli and food are equal.

This study extended prior research by including not only conditions with equal versus unequal exchange delays but also conditions with equal versus unequal terminal reinforcer (food) delays. The results of these conditions were generally comparable to those seen with equal and unequal exchange delays: greater sensitivity to reinforcer amount when food delays were equal, and greater sensitivity to reinforcer immediacy when food delays were unequal. As such, the present findings are consistent with prior research showing sensitivity to food amounts with equal food delays and to food delays with equal food amounts (Grace, 1995; Logue, Rodriguez, Peña-Correal, & Mauro, 1984; Snyderman, 1983). Such sensitivity to exchange and food delays reported here is also consistent with prior research on second-order token reinforcement schedules showing sensitivity to exchange-schedule (Foster, Hackenberg, & Vaidya, 2001; Kelleher, 1957; Webbe & Malagodi, 1978) and food-schedule (Malagodi, Webbe, & Waddell, 1975) variables.

Of additional interest are conditions in which delays to the exchange stimulus were manipulated independently of food delays (Part 2). The results of both of these comparisons (UED/efd vs. EED/efd and EED/ufd vs. UED/ufd) address the separate contributions of the exchange stimulus and of the terminal reinforcer (food). Viewed as an extended chained schedule (Kelleher & Gollub, 1962), the exchange delay is the delay to the terminal link in the presence of which food is available. As such, the exchange stimulus should acquire conditioned reinforcing strength, as has been shown with other food-correlated stimuli on self-control procedures (Mazur, 1995, 1997).

If the exchange stimulus was serving as a conditioned reinforcer, then one would predict (a) less extreme preference for the smaller reinforcer under EED/ufd than under UED/ufd, owing to the longer delay to the exchange stimulus on trials with smaller-reinforcer choices; and (b) less extreme preference for the larger reinforcer under UED/efd than under EED/efd, owing to the

shorter delay to the exchange stimulus on trials with smaller-reinforcer choices. These predictions were generally confirmed in Part 2 of the experiment for 3 of 4 pigeons (710, 743, and 777). Consistent with (a), under conditions in which food delays favored smaller-reinforcer choices, preference for the smaller reinforcer was seen under fewer conditions when exchange delays were equal (four of eight EED/ufd conditions) than when exchange delays also favored smaller-reinforcer choices (nine of nine UED/ufd conditions, Parts 1 and 2 combined). Consistent with (b), under conditions in which food delays were equal, preference for the larger reinforcer was seen under fewer conditions when exchange delays were shorter for smaller-reinforcer choices (three of nine UED/efd conditions) than when exchange delays were equal (12 of 13 EED/efd conditions, Parts 1 and 2 combined).

While generally in line with a conditioned reinforcement view, some of the results also follow from a consideration of relative food delays. To hold exchange delays constant across UED/ufd and EED/ufd conditions in Part 2, it was necessary to increase the food delays for smaller-reinforcer choices from 0.3 s in UED/ufd conditions to a value slightly greater than the token delay for larger-reinforcer choices in EED/ufd conditions (about 12 to 18 s, across subjects). Increasing the smaller-reinforcer delay while holding constant the larger-reinforcer delay at 30 s changes the relative value of the two options. According to Mazur's (1987) model, the value of a reinforcer is determined by the following function:

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

where  $V$  is reinforcer value,  $A$  is reinforcer amount, and  $D$  is reinforcer delay. As the smaller-reinforcer delay increases, the relative value of the two options converge. At delays within the range of values used here (12 to 18 s) under EED/ufd conditions, the model predicts the observed preference for the larger reinforcer when the larger-reinforcer food delay was 30 s (three of four cases). It also accurately predicts the preference reversal for the smaller reinforcer when the larger-reinforcer delay was 50 s (three of four cases).

Such patterns are also generally in accord with data from more conventional concurrent-chains procedures (Green & Snyderman, 1980).

Choice patterns under conditions with unequal food delays may therefore reflect differences in relative food delays instead of, or in addition to, differences in exchange delays. Differences in choice patterns between UED/efd and EED/efd conditions, however, are less susceptible to such an interpretation. Because food delays were equal for both options, Mazur's (1987) model predicts preference for the larger reinforcer under both condition types. The model can also be applied to delays to conditioned reinforcers (Mazur, 1995, 1997). Under UED/efd and EED/efd conditions, the exchange delays differ (0.3 s vs. 30 s or 50 s, respectively). Thus, when applied to exchange delays rather than food delays, the model predicts the observed preference for the smaller reinforcer under UED/efd conditions and for the larger reinforcer under EED/efd conditions.

Preference for the smaller reinforcer under UED/efd conditions was generally stronger when food delays for both options were 30 s than when they were 50 s. This result runs counter to the results of prior studies showing increased preference for the larger reinforcer with increases in equally-delayed food reinforcers (Ito & Asaki, 1982; Navarick & Fantino, 1976; Snyderman, 1983). Such preferences are also not predicted by a literal application of Mazur's model to exchange or food delays, as the absolute values of these delays were the same under 30 and 50 s food delays. The results do follow, however, from a consideration of the exchange delays *relative* to the food delays. Increasing the food delays from 30 to 50 s decreases the relative delay to the exchange stimulus, which is consistent with the enhanced preference for the smaller reinforcer obtained here (see Davison & Smith, 1986, for similar effects with food reinforcers).

Taken as a whole, then, the results are broadly consistent with an interpretation based on relative delays to food and food-correlated (exchange) stimuli. Parametric manipulations of these variables will be necessary to assess in more precise quantitative detail the generality of this view. The present

analysis is also limited by the extreme preferences generated by these procedures, which may have masked stronger conditioned reinforcing effects of the exchange stimuli. These procedures were selected to maintain consistency with prior work, but future work should utilize procedures that permit more graded measures of preference, such as concurrent-chains or adjusting procedures, that are better suited to detecting conditioned reinforcement effects (Fantino, 1977; Mazur, 1997).

Another topic for future research concerns the role of the tokens. If tokens are functioning analogous to points in experiments with human subjects, then one might expect that the number of, and delay to, tokens would acquire important reinforcing and/or discriminative functions in their own right. Because the present study was designed to assess the effects of the exchange delays apart from the food delays, the token delays were held constant across conditions, and exchanges occurred every trial (i.e., tokens did not accumulate across trials). Prior research suggests that discriminative functions of tokens are enhanced under conditions in which tokens are allowed to accumulate prior to exchange (Foster et al., 2001; Jackson & Hackenberg, 1996) in much the same way that points accumulate within a session in experiments with humans. Determining more precisely the role of the tokens on such procedures remains an important challenge for future research.

In summary, the overall choice patterns are in agreement with prior results on standard self-control procedures with token reinforcers: choices varied as an orderly function of delays to the exchange stimulus and/or to food (Jackson & Hackenberg, 1996). By disentangling the separate contributions of exchange and terminal-reinforcer delays, the present results provide a more complete picture of the critical variables operating in token-based self-control procedures.

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