CHOICE BEHAVIOR OF RATS IN A CONCURRENT-CHAINS SCHEDULE: AMOUNT AND DELAY OF REINFORCEMENT

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Rats were exposed to concurrent-chains schedules in which the terminal links were equal fixed-interval schedules terminating in one or three food pellets. Choice proportions for large reward increased with increases in delay intervals programmed on fixed-interval schedules and supported the predictions derived from a general choice model originally formulated by Fantino and later developed by Navarick and Fantino. In addition, a functional equivalence of two alternatives was established by increasing delay intervals with large reward, whereas delay intervals for small reward were held constant. Functionally equivalent delay intervals with large reward, for each delay interval with small reward, can be described by a power function with exponent smaller than 1.0. A better prediction of choice proportions resulted when this function was used to derive predicted choice proportions.

Key words: choice, amount and delay of reinforcement, functional equivalence, concurrent-chains schedule, FI schedules, lever press, rats

The choice between alternatives differing in amount and delay of reinforcement has been studied within the framework of "self-control" (Rachlin, 1974; Rachlin & Green, 1972). Preference for the delayed large reward has been called "self-control" (e.g., Rachlin, 1974), whereas preference for the immediate small reward has been called "impulsiveness" (e.g., Ainslie, 1974). Most studies have been concerned with a general choice model describing these different choices and focused on a concurrent-chains schedule as a conventional choice procedure (Baum & Rachlin, 1969; Fantino, 1969; Navarick & Fantino, 1976).

Baum and Rachlin (1969) proposed that the value of two alternatives is proportional to the amount of reinforcement and inversely proportional to the delay of reinforcement:

$$\frac{V_1}{V_2} = \frac{A_1}{A_2} \cdot \frac{D_2}{D_1} = \frac{R_1}{R_2} \quad (1)$$

where V is the value of an alternative, A is the amount of reinforcement, D is the delay of reinforcement, and R is the number of re-

sponses to that alternative. Equation 1 predicts that subjects will chose Alternative 1 whenever $A_1 \cdot D_2 > A_2 \cdot D_1$ and Alternative 2 whenever $A_1 \cdot D_2 < A_2 \cdot D_1$. The predictions derived from Equation 1 are consistent with previous studies of commitment (Ainslie, 1974; Rachlin & Green, 1972) and with the results of a simple concurrent-chains schedule (Navarick & Fantino, 1976).

On the other hand, Navarick and Fantino (1976) presented an alternative choice model originally formulated by Fantino (1969), who proposed that choice for an alternative depended on the reduction in overall time to reward correlated with choice for the alternative:

$$\begin{aligned} \frac{R_1}{R_1 + R_2} &= \frac{T - t_1}{(T - t_1) + (T - t_2)} \\ &= 1 \quad (\text{when } t_1 < T, t_2 < T) \\ &= 0 \quad (\text{when } t_1 > T, t_2 < T) \end{aligned} \quad (2)$$

where R is the number of responses, t is the delay interval, and T is the average time to reward from the onset of the initial links. Equation 2, however, lacks a parameter for amount of reinforcement. Navarick and Fantino (1976) assumed that rate and amount of reinforcement (defined by the duration of access to the reinforcer) are functionally equivalent

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and suggested that reinforcement magnitude could be transformed to a time parameter. For example, when the terminal links are fixed-interval (FI) 5-sec schedules terminating in 4.5 sec of reinforcement on the left and 1.5 sec on the right, it was assumed that in one case the FI 5-sec schedule with 4.5 sec of reinforcement would be equivalent to an FI 1.7-sec schedule with 1.5 sec of reinforcement. Based on this transforming procedure, Equation 2 seems applicable to the situations where amount of reinforcement is manipulated.

Similar predictions are derived from both Equations 1 and 2 when delays are unequal. However, with equal delays, the predictions of the two equations differ; Equation 2 predicts increasing preferences for large reward with increases in delay interval, whereas preferences are constant regardless of delay interval in Equation 1. Navarick and Fantino (1976) examined the applicability of Equations 1 and 2 to the situation where pigeons were given a choice between 4.5 sec and 1.5 sec of reinforcement with equal delay intervals. The results supported the prediction of Equation 2 by showing that preferences for large reward increased with increases in delay interval.

The present experiments examined whether Equation 2 is applicable to choice behavior of rats, which have not usually been studied in concurrent-chains schedules (e.g., Fantino & Navarick, 1974). The present experiments differed especially from the studies with pigeons in that amount of reinforcement was defined by number of food pellets rather than access time to the reinforcer. Therefore, one problem was whether number of food pellets could be transformed to a parameter equivalent to access time to the reinforcer.

EXPERIMENT 1

In Experiment 1, rats chose between one and three food pellets with equal delays.

METHOD

Subjects

Fourteen experimentally naive male albino rats of the Wistar strain, approximately three months old at the beginning of the experiment, were maintained at about 80% of their free-feeding body weights.

Apparatus

A chamber (25 by 25 by 31 cm) with two retractable levers was used. The levers (2.5 cm wide, .2 cm thick) intruded 2.5 cm into the chamber and were mounted 11 cm apart (center to center) and 5 cm above the floor on the front wall. Two 24-V DC lamps were located separately, 4.5 cm above each lever, on the front wall. Each lever could be retracted by a 24-V DC solenoid during which the lamp for the retracted lever was off. A minimum force of about 15 g (.15 N) was required to operate either lever. A recess (5 by 5 by 2.5 cm) was located 1 cm above the floor on the front wall and was illuminated by a 24-V DC small lamp for 6 sec each time a reinforcer (a 45 mg food pellet) was delivered into the recess. The whole chamber was enclosed in a sound-attenuating chest, and masking noise was provided by an exhaust fan. A logic module system, located in an adjacent room, controlled the experiment and recorded events.

Procedure

Preliminary training. Rats were initially trained to press the right lever by the method of successive approximations, and then each press on either the right or left lever was reinforced for several sessions. Only one lever (either right or left) was available at any time during this and the following phase of training. Thereafter, each lever press retracted the lever and produced food. To reduce position preferences, the same number of reinforcers was provided for each lever during the preliminary training.

Concurrent-chains schedule. A concurrent-chains schedule was then introduced, in which two equal variable-interval (VI) schedules arranged access to the terminal links. When the terminal link on one side became available, the VI timer associated with that side stopped operating, while the alternate timer continued to operate. Entry into a terminal link occasioned three events: (1) the lever retracted on the side not pressed; (2) the lamp for the retracted lever was off; (3) the VI timer associated with the retracted lever stopped operating. Further responding on the remaining lever produced food according to a fixed-interval (FI) schedule in that terminal link. When food was delivered, the remaining lever retracted and the lamp was off for 6 sec in either

reinforcement condition (one or three food pellets). Following the 6-sec reinforcement period, both levers were inserted and another cycle began. Both VI timers restarted at this time, except that if both timers had previously arranged access to their respective terminal links, the terminal link not entered remained available upon return to the initial links.

The VI schedules in the initial links were 5 sec initially and were then increased to 60 sec over several sessions. During this phase, rats chose between equal amounts of reinforcement (one food pellet) and equal delays of reinforcement (5 sec). Choice proportions with equal amounts and equal delays of reinforcement did not deviate from .50 by more than .05. Then, rats were exposed to the first condition, in which the amount of reinforcement was increased to three food pellets on whichever lever had the lower choice proportion in the previous condition. Delays of reinforcement programmed on the FI schedule were 5, 10, 20, and 40 sec, respectively. In the first condition,

the delay of reinforcement was either 5, 10, or 20 sec. The rats served in a replication design in which each rat was exposed to two or three delay values. The order of presentation of the delays is described with the results (see Figure 1).

Equal terminal-link schedules were presented until the daily choice proportions satisfied the following stability criterion: after 14 days (and every day thereafter until stability was achieved), the choice proportions for the last six sessions were divided into three successive blocks of two sessions. Choice proportions were considered stable when (a) the means of three blocks did not differ from each other by more than .05; and (b) there was neither an upward ($\bar{X}_1 < \bar{X}_2 < \bar{X}_3$) nor a downward ($\bar{X}_1 > \bar{X}_2 > \bar{X}_3$) trend in the block means. Each daily session consisted of 30 cycles.

RESULTS

Figure 1 shows preferences for large reward at each delay of reinforcement. Data are means

Fig. 1. Mean choice proportions for three-pellet reward over one-pellet reward at each delay interval. Brackets indicate standard deviation.

Fig. 2. Preference for large reward under equal delays, as a function of delay. The solid line shows mean choice proportions at each delay.

over the last six sessions. In most cases, preferences for large reward increased with increases in delay interval (e.g., from 5 to 40 sec), and most rats' preferences decreased when the delays were reduced to initial values, indicating that the preferences were reversible depending on the delays of reinforcement. But, three rats (R12, R13, and R19) failed to reverse preferences when the delays were reduced, resulting in increasing choice proportions independent of the delay. Rat R15 did not change preference when the amount of reinforcement was changed to three food pellets, whereas preference changed when the delays were increased to 20 sec and then reduced to 5 sec. Except for these rats, increasing preference with increases in delay intervals is clearly shown in Figure 2, where original and replication data are combined for each rat. The solid line shows mean choice proportions for each delay interval.

DISCUSSION

These results are consistent with those of Navarick and Fantino (1976) and further support Equation 2, which predicts increasing choice proportions for the larger reward as a function of delay interval.

Navarick and Fantino's experiment and the present Experiment 1 assume the linear equivalence of amount and delay of reinforcement. However, Green and Snyderman (1980), using a concurrent-chains schedule, found differential

effects of amount and delay of reinforcement on choice behavior. They also provided a possible measure of the relative effects of amount and delay of reinforcement based on a multivariate power function (e.g., Baum, 1974). A better fit to the data was obtained by assigning a larger weighting to the delay of reinforcement, indicating that delay of reinforcement is a more potent determinant of choice than is amount. Relative ineffectiveness of reward magnitude on choice is also found in the context of concurrent schedules (Fantino, Squires, Delbrück, & Peterson, 1972; Schneider, 1973; Todorov, 1973). These results question the assumption that amount and delay of reinforcement are linearly equivalent in their effects on choice. Therefore, it would be preferable to assess this question empirically in the context of concurrent-chains schedules with different amounts and delays of reinforcement. Experiment 2 attempted to find an empirical correspondence between amount and delay of reinforcement.

EXPERIMENT 2

In Experiment 2, functionally equivalent combinations of amount and delay were found by increasing delay intervals for large reward, while delay intervals for small reward were held constant.

METHOD

Subjects and Apparatus

Ten male albino rats of the Wistar strain were maintained at approximately 80% of their free-feeding body weights. Of the ten rats, seven had served in Experiment 1. The remaining rats were experimentally naive. The same apparatus was used as in Experiment 1.

Procedure

The same concurrent-chains schedule was in effect as in Experiment 1. The experiment addressed the question: how long a delay for the larger of two rewards will be equally preferred to a fixed shorter delay for the smaller reward? Initially, choice proportions for the larger reward were determined under equal-delay conditions. Then, delays for the larger reward were increased until the preference for the larger reward reached about .50, while delays for the smaller reward were held constant. The acceptable range of values was arbitrarily

designated as .45 to .55. The step size of increased delays varied across the values of small-reward delay; the step size was 3 sec when delay to the small reward was 5 sec, 5 sec when it was 10 or 20 sec, and 10 sec when it was 40 sec. One or more increases were made depending on the choice proportions. Changes in delay for the larger reward were made when the daily choice proportions satisfied the following criterion: after five sessions (and every day thereafter until the criterion was achieved), the delay intervals were increased when (a) the mean of these five sessions did not reach .45 to .55; (b) there was no downward trend in the daily choice proportions.

For the subjects which had served in Experiment 1, testing began after the completion of the last condition in Experiment 1. The naive subjects were initially exposed to the same preliminary training as in Experiment 1 and then given baseline training with equal delays in a concurrent-chains schedule. Testing was carried out at one or two delay values. In the

latter case, second testing was carried out after the choice proportions with equal delay intervals satisfied the same stability criterion as in Experiment 1. Thirteen data points were obtained in the present experiment. The delays for each rat are shown in Table 1. Each daily session consisted of 30 cycles.

RESULTS

The choice proportions for the larger reward reached about .50 with increases in the delay intervals preceding the larger reward. Thus, in all rats, functionally equivalent combinations of amount and delay were obtained. These results are shown in Table 1 for each rat. The choice proportions in Table 1 were obtained by dividing the initial-link responses for the larger reward by the total initial-link responses. The choice proportions with equal delay intervals were based on the last six sessions, whereas the choice proportions during testing were based on all five sessions or the last five sessions if the condition lasted for

Table 1
Summary of Data in Experiment 2.

Subject	Delay (Sec)		Reward	Sess.	Choice Proportion	Initial Link		Terminal Link		Reinf. R/L
						R	L	R	L	
R11	10 (R)	10 (L)	1 (R) 3 (L)	27	0.74	99	278	146	159	14/16
	10	15		5	0.69	117	257	125	231	14/16
	10	25		5	0.61	116	181	154	437	14/16
	10	30		9	0.48	149	138	165	463	14/16
R13	5 (R)	5 (L)	1 (R) 3 (L)	17	0.77	168	573	147	127	14/16
	5	8		5	0.74	194	541	139	208	15/15
	5	11		5	0.72	185	502	130	278	14/16
	5	20		5	0.73	155	409	128	382	14/16
	5	26		5	0.64	188	338	134	408	15/15
	5	32		6	0.49	196	185	146	472	15/15
R14	10 (R)	10 (L)	1 (R) 3 (L)	21	0.84	63	334	110	198	12/18
	10	15		5	0.86	64	390	130	311	13/17
	10	25		5	0.79	88	335	153	567	14/16
	10	35		5	0.62	169	260	168	737	14/16
	10	40		5	0.50	205	204	178	769	15/15
	40 (R)	40 (L)		18	0.86	60	375	455	773	15/15
	40	60		5	0.82	61	286	535	1191	14/16
	40	80		5	0.85	46	256	451	1485	14/16
	40	100		9	0.55	131	159	583	1597	14/16
R15	5 (R)	5 (L)	1 (R) 3 (L)	16	0.56	239	312	104	141	15/15
	5	8		5	0.60	243	365	113	224	15/15
	5	11		5	0.56	239	305	137	280	14/16
	5	14		6	0.51	342	350	122	309	15/15
	20 (R)	20 (L)	1 (R) 3 (L)	15	0.83	137	681	279	410	15/15
	20	30		5	0.77	126	423	244	487	14/16
	20	45		5	0.70	152	363	275	633	15/15
	20	60		8	0.52	194	213	251	814	15/15

Table 1. Continued

Subject	Delay (sec)		Reward	Sess.	Choice Proportion	Initial Link		Terminal Link		Reinf. R/L
						R	L	R	L	
R16	10 (R)	10 (L)	3 (R) 1 (L)	14	0.82	687	147	135	183	15/15
	15	10		5	0.82	655	146	200	182	15/15
	20	10		5	0.77	635	187	284	207	16/14
	25	10		5	0.69	507	227	304	193	15/15
	35	10		5	0.60	388	262	425	207	15/15
	40	10		5	0.51	331	318	489	209	15/15
R17	20 (R)	20 (L)	1 (R) 3 (L)	15	0.80	133	542	153	111	14/16
	20	30		5	0.83	121	609	121	208	13/17
	20	40		5	0.81	131	568	179	332	14/16
	20	50		5	0.74	153	445	167	515	14/16
	20	60		5	0.64	171	306	100	583	15/15
	20	70		8	0.52	338	366	37	865	15/15
R20	40 (R)	40 (L)	1 (R) 3 (L)	15	0.87	29	191	347	686	12/18
	40	60		5	0.85	30	173	338	956	12/18
	40	80		5	0.77	47	155	391	1171	13/17
	40	100		10	0.53	54	60	499	1009	15/15
R23	5 (R)	5 (L)	3 (R) 1 (L)	24	0.65	122	67	64	52	16/14
	8	5		5	0.64	128	72	105	55	16/14
	11	5		5	0.60	129	85	143	57	15/15
	14	5		5	0.61	125	80	166	53	15/15
	20	5		5	0.58	127	93	255	60	15/15
	23	5		5	0.54	109	95	215	55	15/15
R39	10 (R)	10 (L)	1 (R) 3 (L)	18	0.69	258	565	145	161	15/15
	10	22		5	0.69	223	504	177	457	14/16
	10	30		5	0.62	322	520	148	571	15/15
	10	36		5	0.47	410	370	169	716	14/16
	40 (R)	40 (L)		15	0.85	126	710	547	1028	13/17
	40	60		5	0.79	200	831	499	1474	12/18
	40	80		6	0.48	448	487	667	1755	14/16
R40	20 (R)	20 (L)	3 (R) 1 (L)	19	0.72	266	105	284	275	16/14
	30	20		5	0.71	330	133	550	348	16/14
	50	20		8	0.50	208	214	686	352	15/15

more than five sessions. In most cases, the delays preceding the larger reward required for equivalence with the smaller reward corresponded qualitatively to the size of the choice proportions in the equal-delay (baseline) condition. In other words, a longer delay interval was required for equivalence, the greater choice for the larger reward in baseline. These results support the assumption that amount of reinforcement (defined by number of food pellets) can be transformed to delay interval.

Figure 3 represents the obtained functionally equivalent delay intervals with large reward as a function of each interval for small reward in logarithmic coordinates. The solid line shows theoretical values derived from the transforming procedure, assuming that amount of reinforcement is transformed to delay interval by the following function: $D_L = 3.0D_s^{1.0}$, where D_L refers to delay for large

reward and D_s refers to delay for small reward, and the constant of three reflects the three to one ratio of food pellets. The dashed line shows a least-squares fit to the data. A linear regression was applied to the log-transformed mean data at each delay value. The least-squares fit yielded the function: $D_L = 7.7D_s^{.68}$. The obtained function accounted for 99% of the data variance. Thus, in the obtained function, the exponent was smaller and coefficient larger than that of the assumed function. This result indicates that functionally equivalent delay intervals are longer than the assumed values at a relatively shorter delay with small reward and shorter at a relatively longer delay with small reward. Thus, the present experiment provides empirical evidence that amount and delay of reinforcement are not linearly equivalent in their effects on choice behavior, and further reveals the in-

Fig. 3. Large-reward delays (ordinate) functionally equivalent to small-reward delays (abscissa) in logarithmic coordinates. The solid line shows the theoretical values derived from the assumed transforming function. The dashed line shows a least-squares fit of a power function to the data.

adequacy of Equation 1 to describe the present data.

DISCUSSION

According to Equation 1, indifference between two alternatives is achieved when the value (V) of one alternative equals that of another alternative (i.e., $A_1 \cdot D_2 = A_2 \cdot D_1$). For example, the obtained function represents indifference between alternatives consisting of 5-sec delay with one food pellet and 23-sec delay with three food pellets. However, this combination of amount and delay of reinforcement is not consistent with prediction of Equation 1 since $A_1 \cdot D_2 = 23$ and $A_2 \cdot D_1 = 15$ (i.e., $V_1 \neq V_2$). The obtained combinations of amount and delay for indifference thus violate predictions of Equation 1 under three of four delay conditions; Equation 1 predicts only the data at 20-sec delay condition. Therefore, the present results indicate the inadequacy of a simple multiplicative relation between amount and delay of reinforcement as in Equation 1 and a linear transformation assumed by Navarick and Fantino (1976).

Table 2 shows the mean absolute deviations between the obtained data for those conditions of Experiment 2 with equal delays (shown in Table 1), and the predictions from the linear

Table 2

Predicted values and mean absolute deviations at each delay interval.

Delay (sec)	Predicted value and (mean absolute deviation)	
	Navarick & Fantino (1976)	Empirical transforming function
5	.58 (.10)	.65 (.07)
10	.67 (.13)	.72 (.07)
20	.83 (.05)	.83 (.05)
40	1.00 (.14)	.95 (.09)
$\bar{X}$	.105	.068

transformation (Navarick & Fantino, 1976) and the present transforming function. A better fit to the data in Experiment 2 was obtained when the present transforming function was used to derive predicted choice proportions. Furthermore, a better fit to the data in Experiment 1 (shown in Figure 2) was also found; mean absolute deviations were .09 with the linear transformation and .06 with the present transforming function. These results demonstrate the adequacy of the present obtained function in transforming reward magnitude into delay interval.

GENERAL DISCUSSION

The main purpose of the present study was to examine whether Equation 2 was applicable to choice behavior of rats. The results of Experiment 1 replicated the Navarick and Fantino (1976) finding that choice proportions increased with increases in delay intervals when delays were equal and extended this finding to the situation where amount of reinforcement was defined by number of food pellets rather than access time to the reinforcer. The results strongly supported Equation 2 by showing that rats chose the larger reward more often as delay interval increased.

According to Equation 2, the slope of the function relating preference to delay interval varies, depending on the transformation of reward magnitudes into delay intervals. Navarick and Fantino (1976) suggested two possible transforming procedures that differed in which reward magnitude (one or three food pellets) was considered a reference. For example, in one case the 5-sec delay with three food pellets is equivalent to a 1.7-sec delay with one food pellet, or in another the 5-sec delay with one food pellet is equivalent to a 15-sec delay with

three food pellets when the terminal links were the FI 5-sec schedule terminating in one or three food pellets of reinforcement on either side. With the former transformation, the predicted choice proportion is .53, whereas it is .58 with the latter. The former transforming procedure thus produces a relatively shallow slope of the function relating preference to delay interval, whereas the latter produces a relatively steep slope. Although Experiment 1 favored the latter transforming procedure, a nonlinear transformation based on the latter procedure was supported by Experiment 2, where functionally equivalent delays to large reward were measured for each delay to small reward.

The results of Experiment 2 clearly show that the transformation of reward magnitude into delay interval is nonlinear (e.g., a power function). In other words, the amount and delay of reinforcement in choice situations differing in these two variables interact in such a way that a power function is applicable. A similar power function was applied to the interaction between amount and delay of reinforcement by Green and Snyderman (1980). Based on a multivariate power function applied to Equation 1, they dealt with differential effects of amount and delay of reinforcement by using a relative measure of the ratio of exponents, (x/y) . In application to Equation 2, this measure was used as a weighting factor to amount of reinforcement; the amount of reinforcement weighted by the ratio of exponents, $(A_1/A_2)^{x/y}$, was multiplied by the delay value in transforming reward magnitude into delay interval. A better fit to the data was obtained using an x/y value of .67. This means that the potency of reinforcer amount is smaller than predicted by Equation 1 and invariant across the delay values. However, the present obtained function reveals that the potency of reinforcer amount is larger at the shorter delays and smaller at the longer delays than predicted by a linear transformation (Navarick & Fantino, 1976). Thus, the present results indicate the potency of reinforcer amount to be variable depending on the delays. Although Green and Snyderman's analysis provides only an *ex post facto* description of choice behavior, the present Experiment 2 provides empirical evidence for the interaction between amount and delay of reinforcement.

The present approach to choice behavior is

a kind of scaling of reward magnitude in terms of delay interval. If the present results adequately reflect the scaling of reward magnitude, the interaction between reward magnitude and delay of reinforcement is described by the following function of a general form: $D_L = kD_s^n$, where k and n are empirical constants. Although values of k and n were found to be 7.7 and .68 in the present study, these parameters may vary depending on reward magnitude used.

With respect to the function describing these interactions, Logan (1965a, b), with a runway apparatus, attempted a similar but more extensive analysis in which rats were given a choice between alternatives differing in amounts and delays of reinforcement. In the first experiment, indifference points were estimated under various combinations of amount (defined by number of food pellets) and delay of reinforcement. Based on these estimates for indifference, he formulated two negatively accelerated functions for amount and delay of reinforcement; $K = 1 - 10^{-.12A}$ for amount and $J = .13D^{-.5}$ for delay, where A is amount in number of food pellets, D is delay in seconds. Unlike the present study, he tentatively assumed an additive rule to combine these two variables (i.e., $K - J$). Logan's functions thus generate gradients in which the effectiveness of amount and delay of reinforcement negatively accelerates across each dimension, whereas the present function deals with the interaction between these two variables when only one combination of reinforcer amount (one vs. three food pellets) was used. Logan's study may have significance in providing equations for describing reward effectiveness of each reinforcement variable (e.g., amount and delay). However, application of Logan's functions to the present choice situation is probably limited by his use of a runway apparatus. Furthermore, Logan's study differed especially from the present experiments in that he assumed an additive relation between amount and delay of reinforcement. Whereas the results of Experiment 2 did not favor a simple multiplicative relation (e.g., Baum & Rachlin, 1969; Navarick & Fantino, 1976), the assumption of a multiplicative relation based on a power-law transformation is supported by the present study as well as Green and Snyderman's (1980) experiment.

Taking these results together, the present study provides a possible method in dealing

with the interaction between amount and delay of reinforcement, although the generality of the present obtained function is limited by the use of only one comparison of reinforcer amount (one vs. three food pellets). Application of the present obtained function to other combinations of reinforcer amount remains to be examined in further research. In any case, if the interaction between the variables of reinforcement (e.g., amount, delay, or rate) is adequately quantified, the differential effects of amount and delay (or rate) of reinforcement can be predicted in the contexts of both concurrent and concurrent-chains schedules.

The results of the present study have some implications for the study of self-control. In general, preference between large delayed and small immediate reward changes from the larger to the smaller reward as a function of delay. This reversal of choice clearly indicates that the reward effectiveness of large delayed and small immediate reward differently declines over time (Ainslie, 1975; Green, Fisher, Perlow, & Sherman, 1981). An important problem of the studies on self-control is to specify an equation for generating gradients in which the reward effectiveness declines as a function of delay. The present Experiment 2 provides a power function with exponent smaller than 1.0 for generating gradient in which the effectiveness of the larger reward (three food pellets) varies with delays. The present obtained function reveals that the reward effectiveness of three food pellets is larger than predicted by a linear transformation at the shorter delays and smaller at the longer delays. Applied to Equation 2, the present obtained function accounts for the finding that preference for the larger reward increased with increases in delays when delays were equal.

Recent studies of self-control focus upon a general choice model describing "impulsiveness," "commitment," or "self-control" as a special case of choice behavior. The present study, along with Navarick and Fantino's (1976) study, provides a strong support for Equation 2 as a general model describing these different aspects of choice behavior, although factors other than reinforcement variables (e.g., amount, delay, or rate), such as a training history, remain to be incorporated (Logue & Mazur, 1981; Mazur & Logue, 1978).

In summary, the present study with rats strongly supported Equation 2, and further,

predicted choice proportions fitted the data better when the obtained power-law transforming function was used instead of the commonly assumed linear function. Therefore, a better prediction of choice proportions under choice situations differing both in amount and delay of reinforcement can be made when the parameters of the transforming function are adequately determined.

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