

PREFERENCE REVERSALS WITH FOOD AND WATER REINFORCERS IN RATS

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Rats were given a choice between a smaller, immediately available reward and a larger reward available after a delay. In one phase, the reward was food and in another phase, the reward was water. Constant delays were added between the choice presentation and the delivery of the reward alternatives. As the time between choice and reward delivery increased from 0 to 25 s, all rats (except one in the water phase) reversed their preference from the smaller, sooner alternative to the larger, later alternative. These findings extend the generality of the preference-reversal animal model to qualitatively different reinforcers. Furthermore, the presence of both impulsive and self-control choices within the same animal is consistent with the view that self-control may be understood as choice behavior, and that species differences in self-control may be differences in degree, not kind.

Key words: preference reversals, choice, self-control, amount, delay, lever-pressing, rat

When offered a choice between a small reward and a larger reward available at the same time, organisms tend to choose the larger reward. Likewise, when offered a choice between an immediate reward and a delayed reward of equal magnitude, organisms tend to choose the immediate reward. These are relatively simple choice decisions. Behavior becomes more difficult to predict, however, when an organism is offered a choice between rewards that differ in both amount and delay. Specifically, which reward will the organism select when the choice is between a smaller-sooner (SS) reward and a larger-later (LL) reward?

In general, when offered a choice between a smaller, immediately available reward and a larger, but delayed reward, organisms tend to choose the smaller-immediate reward over the larger-later reward (e.g., Rachlin & Green, 1972). When an equivalent, constant delay is added before both the SS and the LL alternative, making the time of choice less temporally proximate to their delivery, animals often come to choose the LL reward over the SS reward (e.g., Green, Fisher, Perlow, & Sherman, 1981). This preference reversal follows from the matching law (Baum & Rachlin, 1969)

$$V_{SS}/V_{LL} = (A_{SS}/A_{LL})(D_{LL}/D_{SS}), \quad (1)$$

where V represents the values of the smaller-sooner and larger-later rewards, A represents the amount, and D represents the delay to the respective rewards. For example, consider a two-pellet food reward available after 1 s (the SS reward) and a six-pellet food reward available after 6 s (the LL reward). In this case, the immediacy of the SS reward makes its value greater than that of the LL reward ($V_{SS}/V_{LL} = 2/1$), and the animal selects the two-pellet food reward. When an equal delay is added prior to both alternatives, however, the preference may reverse. For example, adding a 10-s delay to both rewards results in a SS reward of two pellets after 11 s, and a LL reward of six pellets after 16 s. In this case, the value of the LL reward is greater than that of the SS reward ($V_{SS}/V_{LL} = 32/66$), and the animal selects the six-pellet food reward.

Preference reversals have been demonstrated in pigeons responding for a food reward. Pigeons overwhelmingly prefer smaller, more immediate rewards. As the delay to the receipt of the two alternatives is increased, however, pigeons reverse their initial impulsive tendency and come to choose the larger-later reward (Ainslie & Herrnstein, 1981; Green et al., 1981). The preference reversal in pigeons demonstrates the effect of the interaction between reinforcer amount and delay on an organism's choice behavior. This interaction is paradigmatic of choice behavior in general, and it may be reasonable to view the preference-reversal paradigm as an animal model of human self-control in which choice of SS is

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impulsive and choice of LL is self-control. For the preference-reversal paradigm to be useful as an animal model of self-control, however, it would be essential to extend the paradigm from an avian species to a mammalian species. Specifically, the generality of the preference-reversal paradigm would be extended if rats, a species phylogenetically closer to humans, were to reverse their preference for a smaller, sooner reward to a larger, later reward as the delay to the two rewards was increased. As yet, no published study has demonstrated unambiguous and consistent preference reversals in the rat.

In addition to extending the generality of the preference-reversal paradigm to the rat, the current study also explored preference reversals with respect to qualitatively different reinforcers (i.e., food and water). To the extent that different physiological systems and environmental pressures regulate the intake of food and water (Hainsworth, 1981), there might be significant differences in preference reversals within the same organism when these two qualitatively different reinforcers are studied. In fact, Chelonis and Logue (1997) have reported that rats do indeed show differences in self-control with respect to water and food rewards, with self-control (i.e., choice of LL) being greater when responding for food. To date, preference-reversal research has not explored choice behavior within the same animal for both food and water rewards. Evidence of preference reversals with both food and water rewards in rats would extend the generality of the preference-reversal model of self-control as well as demonstrate the robustness of the phenomenon.

METHOD

Subjects

Six experimentally naive female Sprague-Dawley rats served as subjects. They were approximately 150 days old and weighed an average of 225 g at the start of the experiment. The rats were housed individually in a colony room maintained at 72° F and 40% relative humidity, with a 12-hr light/dark cycle. Prior to training, the rats' access to food and water was gradually reduced until they were maintained on approximately 10 g of laboratory

rodent chow and 15 to 20 mL of water per day, presented after each daily session.

Apparatus

Training and daily experimental sessions were conducted in a standard operant chamber measuring 26 cm wide, 28 cm long, and 30.5 cm high. The chamber was housed in a light- and sound-attenuating box. A ventilation fan operated continuously to mask extraneous noise. The test chamber was equipped with two retractable levers, one mounted on the right side of the front panel, the other on the left side of the front panel. The levers were 4 cm wide and projected 2 cm into the chamber when extended. The center of each lever was positioned 3.5 cm from its respective adjoining wall (left or right) and 7 cm above the metal grid floor. The levers required a force of approximately 0.2 N to operate.

A triple-cue lamp with green, white, and red caps fitted over 7-W miniature bulbs was centered 2 cm below the stainless steel ceiling on the front panel. The middle (white) cue lamp served as the houselight, and the left (green) and right (red) cue lamps signaled the SS and LL alternatives, respectively. A partitioned reinforcer magazine was centered on the front panel 2 cm above the grid floor. Its opening measured 6 cm wide by 4 cm high. A 0.08 mL dipper delivered water reinforcement into the left portion of the magazine, and 45-mg Noyes rodent-formula pellets were delivered into the right portion of the magazine. During periods of reinforcement, the appropriate portion of the magazine was illuminated with a 7-W miniature bulb. Experimental events and data recording were controlled with a Medstate® notation program and a MED-PC™ system interfaced to a computer located in an adjacent room.

Procedure

Rats were trained to eat from the magazine. Food pellets were then used to shape the lever-press response by the differential reinforcement of successive approximations. After lever pressing was established to both levers using food pellets, the rats were trained to drink when water was presented in the magazine. Water reinforcement was then delivered contingent upon lever pressing.

After the rats were trained to respond for

both food and water, they were exposed to a discrete-trials choice procedure in which they could choose between reinforcers that differed in amount and delay. Specifically, responses on the left lever produced access to a smaller-sooner (SS) reinforcer, and responses on the right lever produced access to a larger-later (LL) amount of the same reinforcer (food pellets or water).

Each trial lasted 60 s, beginning with the extension of one or both of the response levers. The rats had 10 s in which to make a response. If no response was made within that period, the lever(s) retracted and the houselight remained illuminated. A single response extinguished the houselight and retracted the extended lever(s). The corresponding cue light (left, green for SS; right, red for LL) was then illuminated for the 1 s immediately following the response as well as the 1 s immediately preceding reinforcer delivery. In the baseline (0-s) delay condition when the SS reinforcer was chosen, and in the amount control condition (see below), the cue light remained illuminated for just the 0.5 s before reinforcer delivery. Food pellets were delivered every 0.2 s, and each water dipper was presented for 2 s. After delivery of the reinforcer (food or water), the magazine light was extinguished and the houselight was illuminated.

Experimental sessions were conducted daily. Each session consisted of five blocks of six trials each (two forced-choice followed by four free-choice trials per block). During the first of each pair of forced-choice trials, only one of the levers, randomly selected, was extended into the chamber. The other lever was subsequently extended for the next forced-choice trial. This procedure ensured that the rats were frequently exposed to both outcomes throughout an experimental session. During free-choice trials, both levers were simultaneously extended into the experimental chamber.

Before the experiment proper began, the values to be used for the SS and LL reinforcers were determined. The SS and LL water reinforcers were 0.5-s delay to one dipper and 10-s delay to three dippers, respectively, for all 6 rats. The SS food reinforcer was 0.5-s delay to two pellets, for all 6 rats. The amount of the LL food reinforcer was four pellets. The delay to the LL food reinforcer was ini-

tially set at 6 s. The final baseline value for the delay to the LL reinforcer was then determined individually for each rat by systematically increasing the delay from 6 s until the rat strongly preferred the SS reinforcer. The criteria for a strong preference required that the delay value be in effect for at least 15 days and that the rat chose the SS reinforcer on at least 70% of the free-choice trials during the last 5 days. The final delay value for the LL food reinforcer was 12 s for Rat 1, 25 s for Rats 2 and 3, 15 s for Rat 4, 30 s for Rat 5, and 20 s for Rat 6. These values then served as the baseline (0-s delay) condition in the experiment proper. The delay values for the LL water reinforcer were not adjusted because all rats met the criteria for strong preference with the initial values.

The rats were studied under four experimental conditions: the baseline (0-s delay) condition, with delay and amount values as just described, as well as 5-, 15-, and 25-s delay conditions in which a constant delay (5, 15, or 25 s) was added before the delivery of both the SS and LL reinforcers. For example, the SS alternative for Rat 1 in the baseline condition of the food phase was two pellets after 0.5 s and the LL alternative was four pellets after 12 s. In the 5-s delay condition for this rat, a constant 5-s delay was added before the delivery of the SS and LL reinforcers, making the choice alternatives two pellets after 5.5 s and four pellets after 17 s.

The rats completed the experimental conditions as well as an amount and delay control condition for both the food and water phases. Half of the rats (Rats 1, 3, and 6) completed the food phase first; the other half (Rats 2, 4, and 5) completed the water phase first. Within the food and water phases, the baseline (0-s) delay was always presented first. The remaining delay conditions were presented in different orders (shown in Table 1).

The amount and delay control conditions were studied after the experimental conditions of the food and water phases had been completed. In the amount control condition, the two choice alternatives differed in amount but not in delay (i.e., 0.5-s delay followed by one dipper vs. 0.5-s delay followed by three dippers in the water phase, and 0.5-s delay followed by two pellets vs. 0.5-s delay followed by four pellets in the food phase). In the delay control condition, the two choice

Table 1

Order in which conditions were studied for each rat. Number of sessions is shown in parentheses.

Rat	Food phase		Water phase	
	Condition	Order (#)	Condition	Order (#)
1	0	1 (30)	0	5 (21)
	5	3 (17)	5	8 (21)
	15	2 (36)	15	6 (17)
	25	4 (33)	25	7 (42)
	Amount Control	9 (26)	Amount Control	11 (14)
	Delay Control	10 (41)	Delay Control	12 (21)
2	0	5 (17)	0	1 (29)
	15	6 (19)	5	4 (19)
	25	7 (38)	15	2 (25)
	Amount Control	10 (29)	25	3 (86)
	Delay Control	11 (41)	Amount Control	8 (25)
			Delay Control	9 (142)
3	0	1 (19)	0	5 (18)
	5	4 (36)	15	6 (43)
	15	2 (39)	25	7 (46)
	25	3 (20)	Amount Control	10 (15)
	Amount Control	8 (14)	Delay Control	11 (25)
	Delay Control	9 (51)		
4	0	5 (16)	0	1 (14)
	5	8 (15)	5	3 (72)
	15	6 (25)	15	2 (35)
	25	7 (37)	25	4 (52)
	Amount Control	11 (15)	Amount Control	9 (25)
	Delay Control	12 (70)	Delay Control	10 (49)
5	0	4 (17)	0	1 (30)
	15	5 (16)	15	2 (28)
	25	6 (25)	25	3 (112)
	Amount Control	9 (48)	Amount Control	7 (31)
	Delay Control	10 (30)	Delay Control	8 (62)
6	0	1 (19)	0	5 (19)
	5	3 (118)	5	6 (15)
	15	2 (24)	15	7 (58)
	25	4 (31)	25	8 (19)
	Amount Control	9 (20)	Amount Control	11 (15)
	Delay Control	10 (17)		

alternatives differed in delay but not in amount (i.e., three dippers after a 25.5-s delay vs. three dippers after a 35-s delay in the water phase, and four pellets after a 25.5-s delay vs. four pellets after 25 s plus the individual baseline LL delay in the food phase). The amount control condition determined that the rats discriminated between the smaller and larger reinforcer amounts, and the delay control condition determined that the rats discriminated the difference in time between when the sooner and later reinforcer alternatives were available.

Rats remained on each condition for a minimum of 15 days and were required to

meet stability criteria before conditions were changed. Stability was determined by dividing the last 9 days of a condition into three blocks of 3 days each. The medians of these blocks could not show an upward or a downward trend. In addition, choice over the last five sessions had to be stable by visual inspection. The order in which conditions were studied and the number of sessions on each are shown for each rat in Table 1.

RESULTS

Percentage choice of the larger, later alternative, number of unreinforced trials, and la-

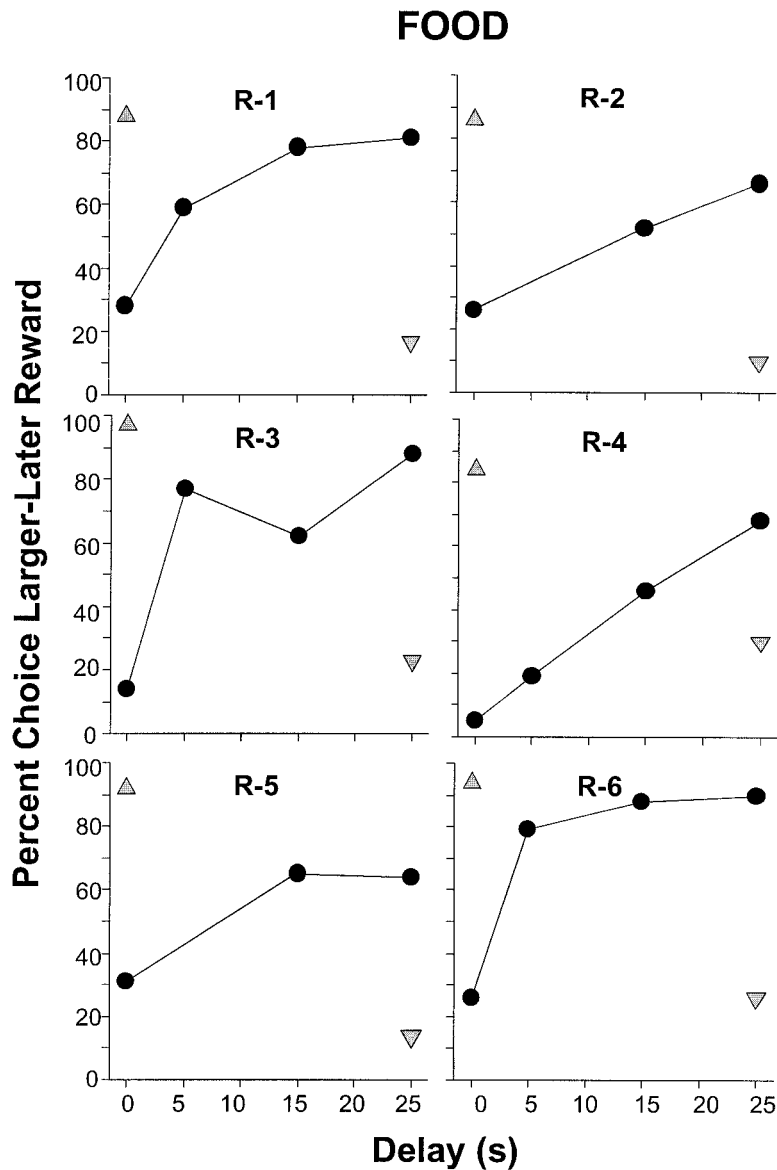


Fig. 1. Percentage choice of the larger-later alternative for each rat when the reinforcer was food. Results from the amount and delay control conditions are represented by the upright and inverted triangles, respectively. Data are the means of the last five sessions of each condition.

tency to respond were calculated for each rat for each of the experimental conditions and amount and delay control conditions for the food and water phases. Data presented are based on the means from the last 5 days of each condition. Figure 1 presents, for each rat, the mean percentage choice of the larger, later alternative for each experimental condition when the reinforcer was food. All of the rats displayed a robust preference rever-

sal, preferring the SS two-pellet food reinforcer at the 0-s delay, and preferring the LL four-pellet food reinforcer when a 25-s delay was added before both outcomes. Mean percentage choice for the LL food alternative for all 6 rats at the 0-s delay was 21.7, whereas at the 25-s delay, the mean percentage choice for the LL food alternative was 76.2.

The triangles in Figure 1 represent the rats' preferences in the two control condi-

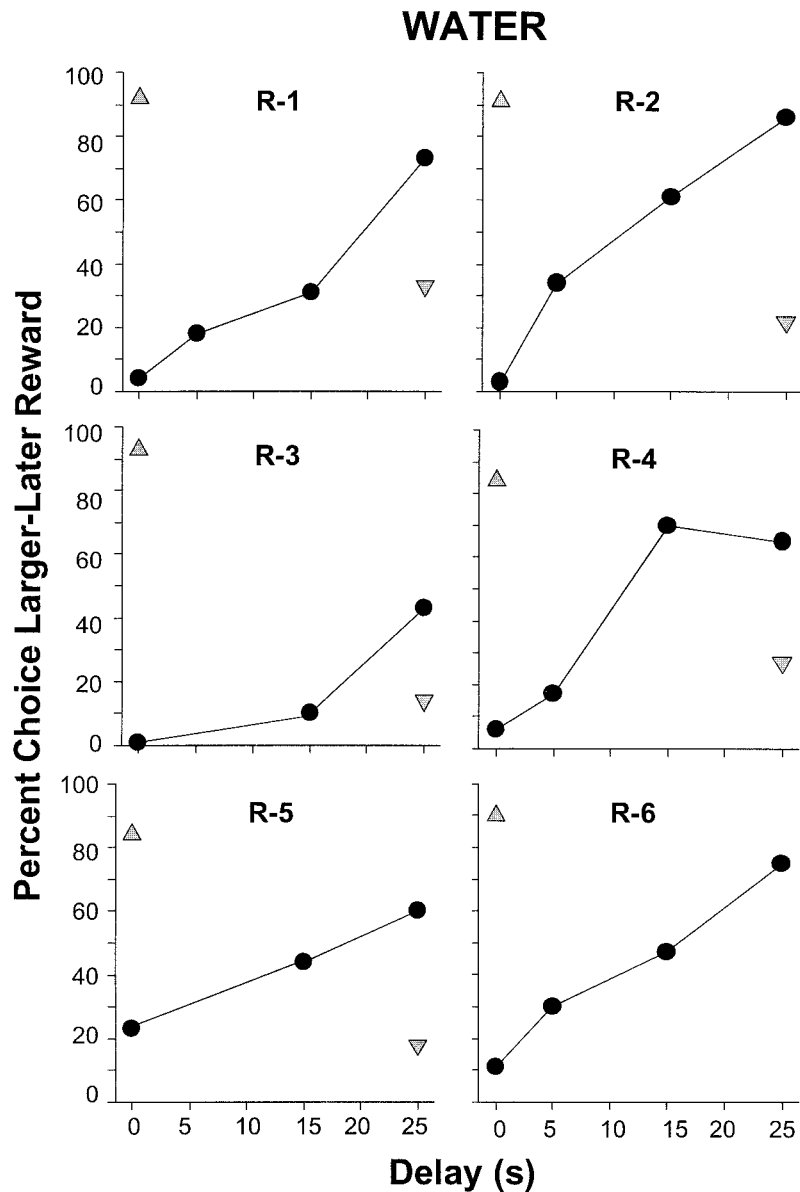


Fig. 2. Percentage choice of the larger-later alternative for each rat when the reinforcer was water. Results from the amount and delay control conditions are represented by the upright and inverted triangles, respectively. Data are the means of the last five sessions of each condition.

tions. All subjects strongly preferred the larger food alternative when the delay to both outcomes was the same (upright triangles), and all preferred the sooner reinforcer when the amount of both outcomes was the same (inverted triangles). These results indicate that the rats discriminated between the different amounts of, and delays to, food reinforcement.

Figure 2 presents, for each rat, the mean percentage choice for the larger, later alternative for each experimental condition when the reinforcer was water. Five of the 6 rats displayed a preference reversal in the water condition, preferring the SS one-dipper water reinforcer at a 0-s delay but preferring the LL three-dipper water reinforcer when a 25-s delay was added before both outcomes. Al-

Table 2

Number of unreinforced trials in each experimental condition for each rat. Data are the means of the last 5 days of each condition.

Rat	Food phase		Water phase	
	Condition	Unreinforced trials	Condition	Unreinforced trials
1	0	0.0	0	0.6
	5	2.4	5	5.8
	15	2.4	15	17.4
	25	19.2	25	12.6
2	0	0.2	0	1.0
	15	0.0	5	1.4
	25	0.0	15	3.0
			25	2.4
3	0	0.2	0	0.2
	5	0.6	15	1.0
	15	17.6	25	1.6
	25	13.8		
4	0	0.2	0	0.8
	5	2.8	5	5.6
	15	12.2	15	6.6
	25	39.8	25	25.2
5	0	0.0	0	0.2
	15	4.0	15	2.6
	25	18.8	25	7.0
6	0	0.2	0	16.0
	5	6.2	5	7.2
	15	12.6	15	23.6
	25	18.0	25	30.2

though Rat 3 did not reverse its preference, it did increase its preference for the LL reinforcer as the constant delay was increased. Mean percentage choice for the LL water alternative for all 6 rats at the 0-s delay was 8% and was 66.7% at the 25-s delay. Again, the results from the delay and amount control conditions indicate that the rats discriminated between the differences in amount of and delay to water, overwhelmingly preferring the larger water reinforcer when both were equally delayed (upright triangles), and preferring the less-delayed water outcome when both were equal in amount (inverted triangles).

Table 2 presents the mean number of unreinforced trials in each experimental condition for each rat. In general, as delay to both outcomes increased, the number of unreinforced trials also increased (except for Rat 2 in the food phase, for whom unreinforced trials remained near zero). Mean unreinforced trials averaged across all subjects

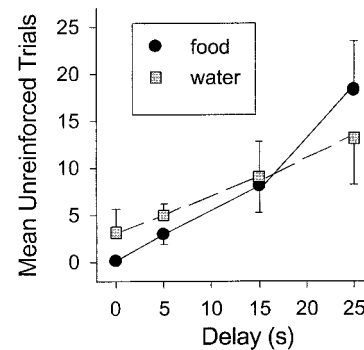


Fig. 3. Mean (\pm SE) number of unreinforced trials, averaged across all rats, from the last five sessions of each experimental condition of the food and water phases.

under the food and water phases are shown in Figure 3.

Figure 4 presents the mean latency to respond, averaged across all subjects for the LL and the SS alternatives in both the food (top) and water (bottom) phases. In general, there was a tendency toward longer latencies as delay increased, for both LL and SS choices under both the food and water phases. There was no consistent pattern across rats with regard to differences in latency to respond for the SS versus the LL reinforcer (see Table 3). For example, Rat 1 generally took longer to respond for the LL alternative in both the food and water phases, whereas Rat 2 generally took longer to respond for the SS alternative in both the food and water phases, and Rat 3 showed no consistent difference in latency between the SS and the LL alternatives.

DISCUSSION

All of the rats reversed their preference from the smaller, sooner two-pellet food reinforcer at the 0-s delay to the larger, later four-pellet food reinforcer when a 25-s delay was added before both outcomes. Likewise, 5 of the 6 rats reversed their preference from the one-dipper water reinforcer at the 0-s delay to the three-dipper water reinforcer when a 25-s delay was added to both outcomes. The finding of preference reversals in the rat extends the previously avian-based animal paradigm to mammals and further extends its generality by demonstrating the phenomenon with qualitatively different reinforcers within the same animal.

Factors such as different deprivation levels,

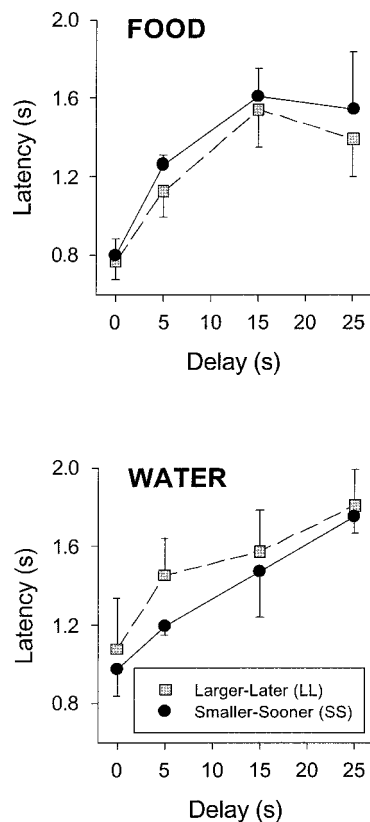


Fig. 4. Mean (\pm SE) latency to respond, averaged across all rats, for the larger-later and smaller-sooner alternatives in both the food (top) and water (bottom) phases.

different amounts of reinforcement, and different amounts of time between the availability of the smaller and larger reinforcers make direct, quantitative comparisons between preference reversals in the food phase with those in the water phase difficult. It may be of interest to note, however, that comparisons of the indifference points (i.e., the delay at which choice switches from the SS to the LL alternative) for the food and water phases reveal that for 4 of the 6 rats (Rats 1, 3, 5, and 6), the indifference point occurred earlier when food was the reinforcer. When the order in which the rats completed the two phases is considered, however, all but 1 rat (Rat 6) had an indifference point at an earlier delay for whichever reinforcer phase (food or water) was experienced first. The order effect makes conclusions regarding possible quantitative differences between preference reversals for food and water premature. Nonethe-

Table 3

Latency to respond (in seconds) to the smaller, sooner (SS) and the larger, later (LL) reinforcer for each rat in each experimental condition. Data are the means of the last 5 days of each condition.

Rat	Food phase			Water phase		
	Condi- tion	Latency		Condi- tion	Latency	
		SS	LL		SS	LL
1	0	0.93	1.15	0	0.92	1.10
	5	1.34	1.36	5	1.31	1.61
	15	1.39	1.63	15	1.61	1.87
	25	1.95	1.89	25	1.87	2.17
2	0	0.63	0.59	0	0.89	0.73
	15	1.32	0.95	5	1.13	1.09
	25	1.30	1.00	15	1.03	0.96
				25	1.60	1.12
3	0	0.77	0.87	0	0.74	0.70
	5	1.33	0.76	15	1.17	1.40
	15	2.02	2.19	25	1.61	1.36
	25	1.11	1.70			
4	0	1.13	0.78	0	1.35	1.14
	5	1.13	1.10	5	1.22	1.20
	15	1.61	1.21	15	1.91	1.67
	25	1.84	1.73	25	1.90	2.06
5	0	0.55	0.52	0	0.54	0.51
	15	1.27	1.30	15	0.80	1.17
	25	0.49	0.68	25	1.50	1.99
6	0	0.79	0.70	0	1.39	2.28
	5	1.25	1.28	5	1.12	1.91
	15	2.06	2.00	15	2.31	2.38
	25	2.56	1.36	25	2.04	2.15

less, *because* food and water consumption are controlled by different physiological systems and are under different environmental pressures (Hainsworth, 1981), the finding of consistent preference reversals with both food and water reinforcers is evidence of the robustness of the preference-reversal phenomenon. Furthermore, the current findings have implications for existing self-control research.

Self-control has been defined as the choice of a larger, more delayed reward over a smaller, more immediate reward (e.g., Ainslie, 1974; Rachlin & Green, 1972). In contrast, the choice of a smaller, immediately available reward over a larger, delayed reward is defined as impulsivity. Much of the previous animal research has focused on the relative impulsivity of rats (e.g., Tobin & Logue, 1994). For example, Tobin, Chelonis, and Logue (1993) reported that when rats were presented with a choice between rewards that differ

in both amount and delay, specifically a small, immediately available liquid reward (sweetened condensed milk) and a larger, more delayed liquid reward, the rats overwhelmingly made the impulsive choice. It has been suggested that the relative impulsivity exhibited by rats may be a result of their evolutionary history (Tobin, Logue, Chelonis, Ackerman, & May, 1996). The evolution of a species in a relatively unstable environment would likely maintain impulsive choices. It has been argued, for example, that discounting future rewards may be an adaptive response to uncertainty in an animal's natural environment (Kagel, Green, & Caraco, 1986). Moreover, in such an environment, a rat's metabolic needs might more likely be met if it chooses to eat small amounts of food frequently rather than wait for a larger amount of food that might never be received (Logue, 1988; but see Cheng, Peña, Porter, & Irwin, 2002).

Given environmental constraints, evolutionary pressures, and the different physiological and control mechanisms involved in feeding and drinking (Hainsworth, 1981), it is not unreasonable to suppose that different processes might underlie the choice behavior of different species. For example, Tobin and Logue (1994) found that when food was used as the reinforcer, the degree of self-control choice exhibited by different species was negatively correlated with metabolic rate: larger species (e.g., humans) exhibited greater self-control than smaller species (e.g., rats and pigeons). Others also have found evidence of greater self-control in relatively larger species (monkeys: Tobin et al., 1996; humans: Forzano & Logue, 1994). Tobin et al. suggested that differences in degree of self-control might indeed be qualitative in nature, resulting from the brain-size to body-weight ratio or a shared phylogeny. As such, species with a smaller brain-to-body-weight ratio (e.g., rats and pigeons) would show greater impulsivity.

In contrast to the relative impulsivity of rats frequently reported in the literature, there are instances of rats' demonstrating self-control. For example, van Haaren, van Hest, and van de Poll (1988) reported that rats overwhelmingly demonstrated self-control when offered a choice between a one-pellet immediate food reward and a three-pellet delayed food reward. That is, the rats chose the larger, later reward on the majority of trials. Other

researchers have reported that rats demonstrate both impulsive and self-control choice (Boehme, Blakely, & Poling, 1986). Specifically, the rats' preferences between a smaller, sooner reward and a larger, later reward depended on the length of a two-lane runway that was traveled prior to delivery of the outcome. Rats preferred a one-pellet immediate food reward when the runway was relatively short, and preferred a four-pellet delayed food reward when the runway was relatively long. Because runway length is correlated with delay to reinforcement, the results of Boehme et al. suggest that rats are generally neither impulsive nor self-controlling. Rather, consistent with the present findings, and as suggested by the preference-reversal literature, self-control is a function of amount of and delay to reinforcement.

This view, that choice between the larger, later alternative and the smaller, sooner alternative changes as a function of the delay to both reward alternatives, supports the idea of quantitative, rather than qualitative differences in self-control across species. That is, decision making should be viewed as the interaction of both amount of, and delay to, choice alternatives. With the addition of the present study, preference reversals have now been demonstrated in pigeons, rats, and humans. The presence of both impulsive and self-controlling choices in an avian species as well as two mammalian species is consistent with the view that self-control may be viewed as choice behavior and that species differences may be differences in degree, not kind.

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