

*DISCOUNTING OF DELAYED FOOD REWARDS IN PIGEONS AND RATS:
IS THERE A MAGNITUDE EFFECT?*

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Temporal discounting refers to the decrease in the present, subjective value of a reward as the time to its receipt increases. Results from humans have shown that a hyperbola-like function describes the form of the discounting function when choices involve hypothetical monetary rewards. In addition, magnitude effects have been reported in which smaller reward amounts are discounted more steeply than larger amounts. The present research examines the cross-species generality of these findings using real rewards, namely food pellets, with both pigeons and rats. As with humans, an adjusting amount procedure was used to estimate the amount of immediate reward judged equal in value to a delayed reward. Different amounts of delayed food rewards (ranging from 5 to 32 pellets in pigeons and from 5 to 20 pellets in rats) were studied at delays varying from 1 s to 32 s. A simple hyperbola, similar to the hyperbola-like mathematical function that describes the discounting of hypothetical monetary rewards in humans, described the discounting of food rewards in both pigeons and rats. These results extend the generality of the mathematical model of discounting. Rates of discounting delayed food rewards were higher for pigeons than for rats. Unlike humans, however, neither pigeons nor rats showed a reliable magnitude effect: Rate of discounting did not vary systematically as a function of the amount of the delayed reward.

Key words: discounting, delay, magnitude effect, adjusting-amount, choice, key peck, lever press, pigeons, rats

Temporal discounting refers to the decrease in the present (subjective) value of a reward as the time until its receipt increases. Temporal discounting, and the form of the discounting function in particular, have been extensively studied in humans (e.g., Green, Fry, & Myerson, 1994; Kirby, 1997; Rachlin, Raineri, & Cross, 1991). In addition, research has established that humans discount smaller delayed amounts of reward more steeply than they discount larger delayed amounts (e.g., Green, Myerson, & McFadden, 1997; Kirby, 1997; Raineri & Rachlin, 1993). Although discounting plays a major explanatory role in the study of choice, perhaps surprisingly it has been the specific topic of relatively few studies involving nonhuman animals. Moreover, the form of the discounting function in humans usually has been measured by deter-

mining the amount of an immediate reward that is equal in subjective value to a delayed reward, but until recently, animal studies have inferred the form of the discounting function using more indirect approaches.

For example, Green, Fisher, Perlow, and Sherman (1981) gave pigeons a choice between 2 s or 6 s of food, with the larger amount delivered 4 s later than the smaller amount. When the delay between the choice and the outcome period was brief (e.g., 2 s, so that the choice was between 2 s of food in 2 s or 6 s of food in 6 s), the pigeons strongly preferred the smaller amount. When the delay was long (e.g., 28 s, so that the choice was between 2 s of food in 28 s or 6 s of food in 32 s), however, the pigeons strongly preferred the larger amount. Green et al. suggested that such preference reversals may be explained by assuming that the value of a delayed reward is discounted and that the temporal discounting function has the form of a simple hyperbola (Mazur, 1987):

$$V = A / (1 + kD) \quad (1)$$

where V represents present (subjective) value, A represents the amount of the delayed reward, k is a parameter that governs the rate of discounting, and D represents the delay until receiving the reward. Similarly, Mazur

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(1987) inferred the form of the temporal discounting function from choice data obtained using an adjusting delay procedure with pigeons, as did Rodriguez and Logue (1988), and in both cases the findings were consistent with Equation 1.

Recently, however, two studies (Mazur, 2000; Richards, Mitchell, de Wit, & Seiden, 1997) have examined the form of the discounting function in nonhuman animals more directly using experimental procedures analogous to those used to map out discounting functions in humans (e.g., Green *et al.*, 1994; Rachlin *et al.*, 1991). Richards *et al.* had rats choose between a smaller, immediate and a larger, delayed water reward. The amount of the immediate reward was adjusted based on the rat's previous choice in order to determine the indifference point (i.e., the amount of immediate reward that was equivalent in value to the delayed reward).

By determining the indifference points at a number of different delays, Richards *et al.* (1997) were able to map out the discounting function for individual animals. Discounting functions were determined for three delayed water amounts in each subject. The discounting functions of all 8 rats were well described by Equation 1. Interestingly, no effect of amount on discounting rate was observed (i.e., the value of k in Equation 1 was not significantly affected by the amount of the delayed reward). Grace (1999) also failed to find an effect of reward amount on sensitivity to delay in pigeons using a concurrent chains procedure and delayed food rewards. These results differ from those obtained with humans, for whom the rate of discounting has repeatedly been shown to decrease as a function of reward amount (e.g., Green *et al.*, 1997; Kirby, 1997; Raineri & Rachlin, 1993).

Mazur (2000) also used an adjusting amount procedure to map out individual discounting functions. He showed that pigeons' discounting of delayed food rewards, like rats' discounting of water rewards (Richards *et al.*, 1997) and humans' discounting of hypothetical monetary rewards (e.g., Rachlin *et al.*, 1991), is described by a hyperbola (Equation 1). Based on a comparison of k values estimated for the different species, Mazur suggested that pigeons discount delayed positive reinforcers more steeply than rats, whereas humans discount positive reinforcers

much less steeply than either of the nonhuman species examined.

Thus research suggests that there are both similarities and differences between species with respect to the discounting of delayed rewards. Perhaps the most striking similarity is that the same mathematical function, a simple hyperbola (Equation 1), describes discounting in all three species (rats, pigeons, and humans). It should be noted, however, that discounting in humans is even better described by a hyperbola-like discounting function in which the denominator is raised to a power:

$$V = A/(1 + kD)^s, \quad (2)$$

where the exponent, s , is assumed to reflect the nonlinear scaling of amount and/or delay (e.g., Myerson & Green, 1995).

With respect to the observed differences in discounting rate, it is important to note that different types of rewards have been used for each of the three species. For example, the rats were studied with water reinforcers whereas the pigeons were studied with food reinforcers. Although humans have been studied most commonly with hypothetical monetary rewards, there is evidence to suggest that their discounting rates may differ depending on the type of reward (e.g., Bickel, Odum, & Madden, 1999; Madden, Petry, Badger, & Bickel, 1997; Odum & Rainaud, 2003). Therefore, it would seem desirable to use reinforcers that are at least qualitatively similar when making comparisons across species.

Finally, the lack of a magnitude effect in rats reported by Richards *et al.* (1997) is potentially significant because magnitude effects have been consistently observed in humans with both monetary and nonmonetary rewards (e.g., Chapman & Elstein, 1995; Green *et al.*, 1997; Kirby, 1997; Raineri & Rachlin, 1993). Moreover, the magnitude effect is especially important theoretically because it represents an anomaly with respect to standard microeconomic theory which predicts exponential discounting functions that are insensitive to the amount of the reward being discounted (e.g., Koopmans, 1960).

The present study examined the temporal discounting of food rewards by rats and pigeons over a greater range of delays and

amounts than studied previously. The purpose of the study was twofold: to compare discounting functions in rats and pigeons using similar procedures and reinforcers (food pellets), and to determine whether rate of discounting is affected by the amount of food reward in rats or pigeons.

METHOD

Subjects

Four female White Carneau pigeons and 4 female SD-strain white rats were individually housed in animal colony rooms with a 12:12 hr light/dark cycle. At the beginning of the study, the pigeons were over 5 years old and the rats were approximately 150 days old, and all animals were experimentally naive. Following magazine training, the pigeons were autoshaped to peck illuminated response keys, and the rats were hand-shaped to press response levers. The pigeons had water and grit continuously available in their home cages and were maintained at 80 to 85% of their free-feeding body weights by means of supplemental feedings after each daily session. The rats had water continuously available in their home cages and were provided 1 hr of access to food following each daily session.

Apparatus

The experimental chambers (Coulbourn Instruments), two for the rats and one for the pigeons, were 30 cm long, 25 cm wide, and 30 cm high. The chambers were located inside sound- and light-attenuating enclosures with ventilation fans. Presentation of stimuli and recording of responses were accomplished using a MED Associates interface and MED-PC[™] for Windows software running on a microcomputer located in an adjacent room.

In the pigeon chamber, three circular response keys, each 2.5 cm in diameter, were mounted on the front wall and required a force of approximately 0.15 N to operate. The right and left choice keys were located 24 cm above the grid floor and 16 cm apart, center to center. The middle key was centered on the wall, 21 cm above the floor. When lit, the middle key was yellow and the left and right choice keys were red and green, respectively. A 7-W white houselight was located in the center of the ceiling. A triple-cue

lamp, which could be illuminated red, green, or yellow, was located 7 cm above the middle key. Pigeon pellets (20 mg) were delivered to two food magazines, each of which was located directly below one of the choice keys and 4 cm above the cage floor. During reinforcement, the operative food magazine was illuminated with white light. Food pellets were delivered at a rate of one every 0.3 s. Infrared photodetectors were used to detect whether there were pellets in the magazine.

In the rat chambers, three 4-cm wide retractable response levers (which could extend 2 cm into the experimental chamber) were mounted on the front wall and required a force of approximately 0.10 N to operate. The right and left choice levers were located 17 cm above the floor and 17 cm apart at their centers. The middle lever was centered on the wall, 15 cm above the grid floor. A 7-W white houselight was mounted on the front wall, 2 cm below the ceiling with its light deflected upward. There were three triple-cue lamps. The left and right cue lamps were located 5 cm directly above the left and right choice levers and could be illuminated red and green, respectively. The center cue lamp was located 7 cm directly above the center lever and could be illuminated yellow. Rat pellets (20 mg) were delivered to two food magazines, each of which was located directly below one of the choice levers and 4 cm above the cage floor. During reinforcement, the operative food magazine was illuminated with white light. Food pellets were delivered at a rate of one every 0.3 s. Infrared photodetectors were used to detect whether there were pellets in the magazine.

Procedure

An adjusting-amount procedure, similar to that originally used in humans (Rachlin et al., 1991) and adapted for animals by Mazur (2000) and Richards et al. (1997), was used. Most aspects of the procedure were the same for both pigeons and rats. The pigeons were studied under four reward-amount conditions: 5, 12, 20, and 32 pellets. The rats were studied under three reward-amount conditions: 5, 12, and 20 pellets. However, 2 of the rats only completed the smallest and largest (5 and 20 pellets) reward-amount conditions. For each of the reward-amount conditions, discounting was studied at six delays to food

Table 1

Order in which each pigeon and rat experienced the reward amount conditions. For each amount condition (5, 12, 20, and 32 pellets), the average number of sessions per delay condition is given in parentheses.

Pigeon				Rat			
P81	P82	P83	P84	R92	R93	R95	R96
5 (26.3)	5 (23.5)	12 (31.2)	12 (38.5)	5 (24.8)	12 (43.3)	20 (52.0)	20 (35.8)
32 (30.7)	20 (38.5)	32 (33.0)	20 (31.2)	20 (43.3)	5 (32.3)	5 (29.2)	12 (24.5)
12 (25.0)	32 (28.2)	5 (21.8)	5 (21.3)		20 (37.3)		5 (33.0)
20 (26.3)	12 (31.8)	20 (34.5)	32 (39.0)				

reinforcement: 1, 2, 4, 8, 16, and 32 s. Within each amount condition, each animal was exposed to a different order of the delays, and the order of the reward-amount conditions differed for each animal (see Table 1). Sessions were conducted daily and consisted of 10 blocks of trials. In the event that all 10 blocks were not completed, the session terminated after 100 min. Each block of trials consisted of two forced-choice trials followed by two free-choice trials. Of every two forced-choice trials, one involved the left, adjusting-amount key/lever, and the other involved the right, standard-amount key/lever. The order of presentation was randomized across blocks.

For the pigeons, the start of a trial was signaled by illumination of the middle key and the houselight. A single peck darkened the middle key and illuminated the two side keys. During forced-choice trials, only one of the side (choice) keys was illuminated, whereas both side keys were illuminated during free-choice trials. The left (red) key served as the adjusting-amount key, and the right (green) key served as the standard-amount key. A response to the standard-amount key darkened the keylight(s) and houselight and initiated the standard delay. The green cue light came on and remained on for the duration of the delay. After the delay, the green cue light was extinguished, the food magazine illuminated, and the standard food amount delivered. A response to the adjusting-amount key darkened the keylight(s) and houselight and illuminated the red cue light for 0.5 s, after which the cue light was extinguished, the food magazine illuminated, and the adjusted food amount delivered. The 0.5 s delay provided a brief interval for presentation of the cue light as well as time for the pigeons to

reach the food hopper before the reinforcement period began (Mazur, 2000).

For the rats, the start of a trial was signaled by the extension of the middle lever and illumination of both the yellow cue light over this lever and the houselight. A single lever press darkened the cue light, retracted the middle lever, and extended the side (choice) levers. During forced-choice trials, only one of the side levers was extended and only its cue light was illuminated, whereas both side levers were extended during free-choice trials and both side cue lights were illuminated. The left lever, which was associated with a red cue light, served as the adjusting-amount lever, and the right lever, which was associated with a green cue light, served as the standard-amount lever. A response to the standard-amount lever darkened the houselight (and the red cue light on free-choice trials), retracted the lever(s), and initiated the standard delay during which the green cue light remained illuminated. After the delay, the cue light was extinguished, the food magazine illuminated, and the standard food amount delivered. A response to the adjusting-amount lever darkened the houselight (and the green cue light on free-choice trials), retracted the lever(s), and initiated a 0.5-s delay, during which the red cue light remained illuminated. After the delay, the cue light was extinguished, the food magazine illuminated, and the adjusted food amount delivered. As with the pigeons, the 0.5-s delay provided a brief interval for presentation of the cue light as well as time for the animals to reach the food hopper before the reinforcement period began.

For both pigeons and rats, food presentations were followed by an intertrial interval (ITI), the duration of which was adjusted so

that the total time for each trial was 70 s. During the ITI, the food magazine remained lit for a minimum of 10 s and until all the food pellets were consumed. After all pellets were consumed and at least 10 s had elapsed, the food magazine light was extinguished and the houselight was turned on.

After every four-trial block (two forced and two free trials), the number of food pellets available from the adjusting alternative might be adjusted for the next trial block, based on the subject's free-choice trials during that previous block. If the standard amount had been chosen on both free-choice trials of the preceding block, then the adjusting amount was increased by one pellet. If the adjusting amount had been chosen on both free-choice trials of the preceding block, then the adjusting amount was decreased by one pellet. If each alternative was chosen once in the preceding two free-choice trials, then the adjusting amount remained unchanged for the following block. For the first session of each delay condition, the adjusting amount began at one pellet. At the start of all subsequent sessions, the adjusting amount of food was determined by the choices made in the last block of trials of the preceding session.

Each condition was in effect for a minimum of 20 sessions. For each animal, a condition was terminated when the data from five consecutive sessions were judged stable. In order to determine stability, each session was divided into two half-sessions of five blocks each, and the mean number of pellets delivered for a response on the adjusting-amount key/lever was calculated for each half session. A condition was terminated when the means for all 10 half-sessions were within plus or minus 2 of the grand mean and there was no visible trend. Table 1 gives the mean number of sessions per delay condition for each animal at each reward amount.

RESULTS

Figure 1 shows the subjective value (i.e., the mean adjusting amount expressed as a proportion of the standard amount) plotted as a function of the time until delivery of the delayed (standard) amount for each pigeon in each amount condition, and Figure 2 shows the corresponding data for each of the rats. As mentioned before, the adjusting-amount reward was presented after a 0.5-s

cued delay to provide time for the animals to reach the food hopper. The adjusting-amount reward was considered to be an immediate reinforcer, and 0.5 s was subtracted from the time until the delayed rewards when plotting the data and fitting the discounting functions. As can be seen, the subjective value of the delayed reward decreased systematically with the time until its receipt. Nonlinear regression analyses revealed that the data were generally well described by hyperbolic discounting functions—the solid curves in Figures 1 and 2. (Because delays were measured in seconds, the values of k provided in these and subsequent figures are in s^{-1} .) The median R^2 for the simple hyperbola (Equation 1) calculated across subjects and conditions was .91 for the pigeons and .74 for the rats. Adding a free parameter (i.e., the exponent in Equation 2) increased the median R^2 for the rats to .87 but did not improve the median R^2 for the pigeons. Analyses of the data for individual animals and conditions indicated that the exponent differed significantly from 1.0 (as assessed by the t -ratio; i.e., the difference between 1.0 and the parameter estimate divided by the standard error of the estimate) in only two cases, the 5-pellet condition for Pigeon 84 and the 20-pellet condition for Rat 96.

For both pigeons and rats, including the 0.5 s in the time to the delayed rewards did not systematically affect the fit of either the simple hyperbola discounting function (Equation 1) or the hyperbola-like discounting function (Equation 2). For Equation 1, including the 0.5 s resulted in a decrease in the median R^2 for pigeons from .91 to .85 and an increase in the median R^2 for rats from .74 to .80. For Equation 2, the median R^2 s showed little change for either the pigeons or the rats. Because there was no systematic difference between fits with and without the 0.5 s, subsequent analyses will focus on the fits of Equation 1 to the data with 0.5 s subtracted from all delays, as shown in Figures 1 and 2.

For summary purposes, Figure 3 shows the group mean subjective value for the pigeons in each of the amount conditions as a function of the time until delivery of the delayed reward, and Figure 4 shows the group mean subjective value for the rats. For the rats, only the 5- and 20-pellet conditions are shown be-

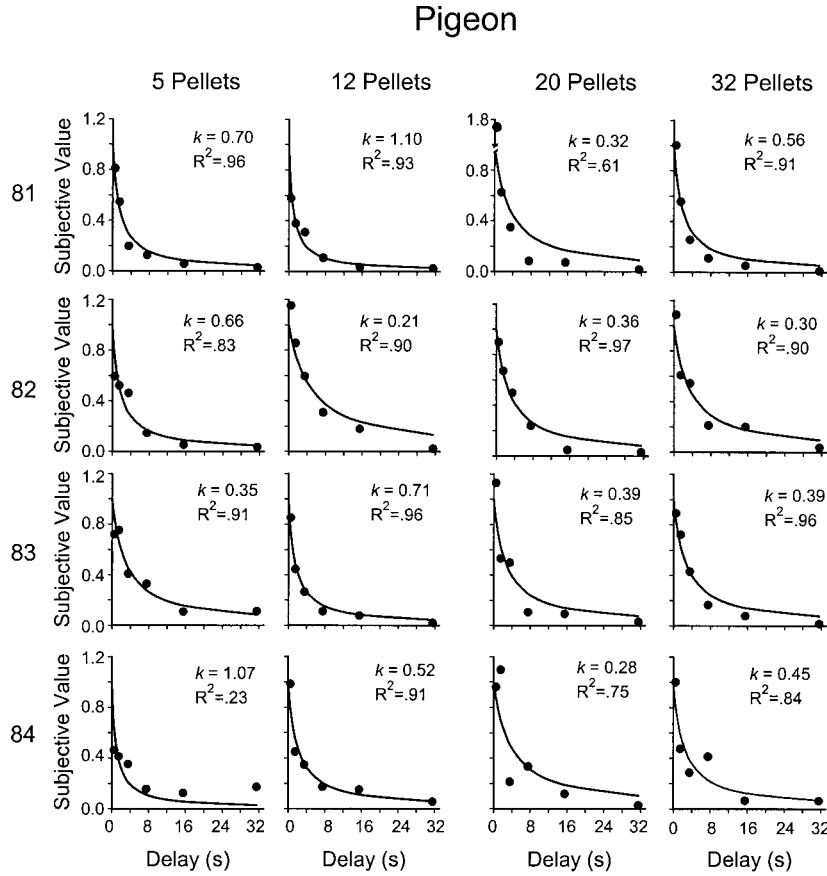


Fig. 1. Discounting functions for individual pigeons. Subjective value was calculated based on the number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. So as to compare behavior in different amount conditions, subjective value is expressed as a proportion of the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the individual data for each amount condition.

cause all 4 rats were studied in these conditions. As can be seen, for both species the data for all amount conditions were well fit by the simple hyperbola (for the pigeons, all four R^2 s were greater than .86; for the rats, both R^2 s were greater than .93).

Two approaches were used to evaluate whether amount of food affected the rate of discounting. The first approach compared the relation between amount of delayed reward and the k -parameter of Equation 1 (which provides an index of discounting rate; larger values of k indicate steeper discounting). Inspection of Figure 5 reveals that there was little systematic effect of amount on rate of discounting for either pigeons or rats. There was, however, a species difference in that pigeons had higher discounting rates than rats. Within each amount condition,

there was little overlap in rates between the two species: The discounting rate parameter for every rat was lower than that for any pigeon except for Rat 96 in both the 12- and 20-pellet conditions.

The second approach to examining the effect of amount on discounting compared the areas under the empirical discounting curve for the different amount conditions (smaller areas indicate steeper discounting). This approach has the advantage of being independent of theoretical assumptions regarding the form of the discounting function. The area measure is calculated by summing the areas of the trapezoids formed by the lines connecting the data points as described in Myerson, Green, and Warusawitharana (2001) rather than by integrating the best-fitting theoretical discounting function (e.g., Equation

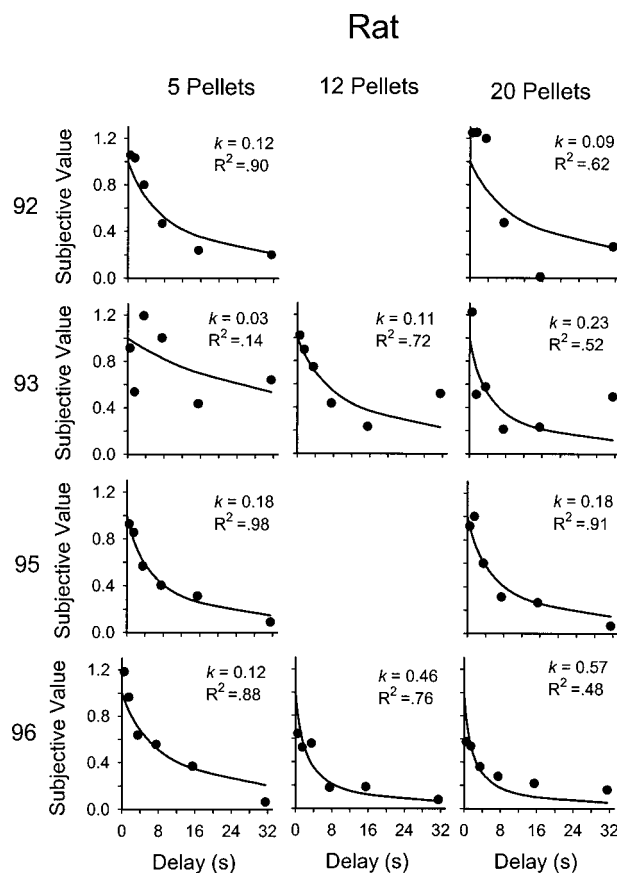


Fig. 2. Discounting functions for individual rats. Subjective value was calculated based on the number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. So as to compare behavior in different amount conditions, subjective value is expressed as a proportion of the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the individual data for each amount condition.

1 or 2). Another potential advantage of the area measure is that it is more normally distributed than the k -parameter, which (at least in humans) is highly skewed. Figure 6 shows the areas under the curve for the pigeons and rats in the different amount conditions. As with the k -parameter, the area measure revealed little systematic effect of amount on discounting, although again there was an apparent effect of species in that pigeons showed smaller areas than rats (indicating steeper discounting by the pigeons).

DISCUSSION

The present study examined the temporal discounting of delayed food rewards using very similar procedures with both pigeons and rats. Notably, these procedures are also

similar to those used to study temporal discounting in humans in that the amount of an immediate reward is adjusted until it is judged equal in value to a delayed reward (e.g., Green et al., 1994; Rachlin et al., 1991). As in humans, the temporal discounting data for both pigeons and rats were well described by a hyperbola (Equation 1). Similar results have been reported with delayed access to grain in pigeons (Mazur, 2000) and with delayed access to water in rats (Richards et al., 1997).

Compared with rats, pigeons in the present study appeared to discount delayed food rewards more steeply, confirming Mazur's (2000) suggestion regarding possible species differences. Mazur's suggestion, however, was based on separate studies of pigeons and rats

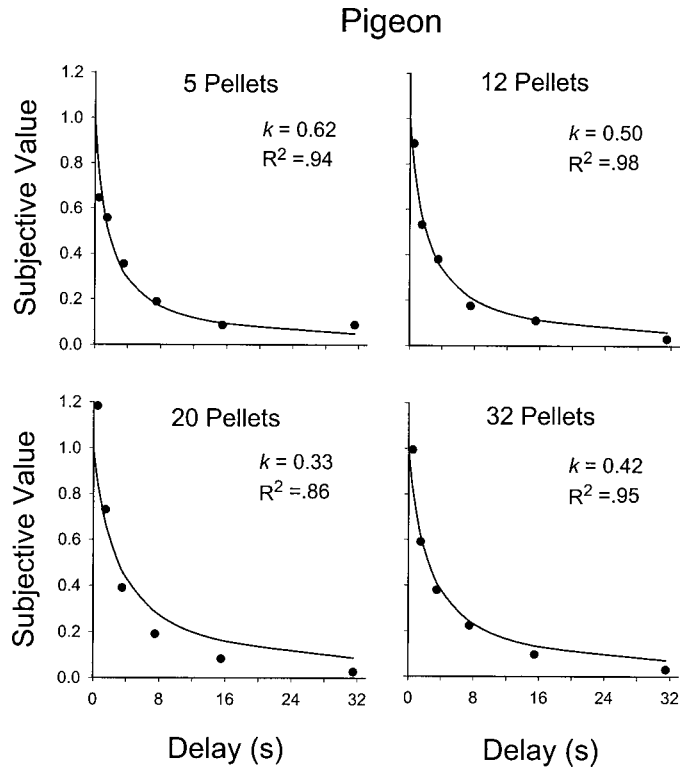


Fig. 3. Discounting functions for pigeons. Subjective value (expressed as a proportion) was calculated based on the group mean number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the group mean data for each amount condition.

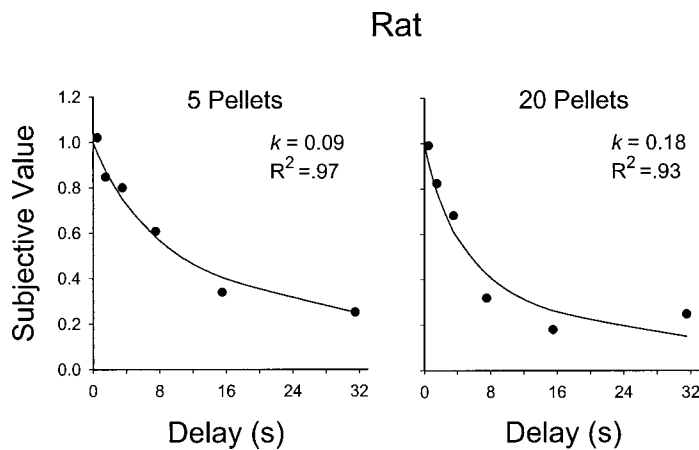


Fig. 4. Discounting functions for rats. Subjective value (expressed as a proportion) was calculated based on the group mean number of pellets delivered immediately that was equivalent in value to the standard, delayed amount. Each curve represents the hyperbola (Equation 1) that best fit the group mean data for each amount condition.

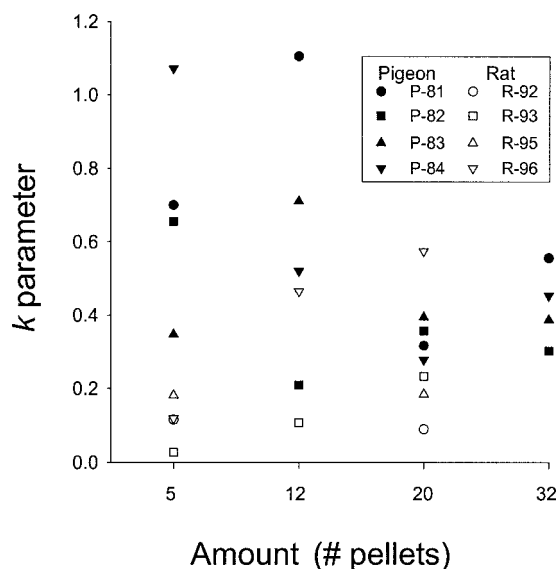


Fig. 5. Estimates of the discounting rate parameter (k) for each subject in each amount condition. Steeper discounting is indicated by higher values of the k parameter.

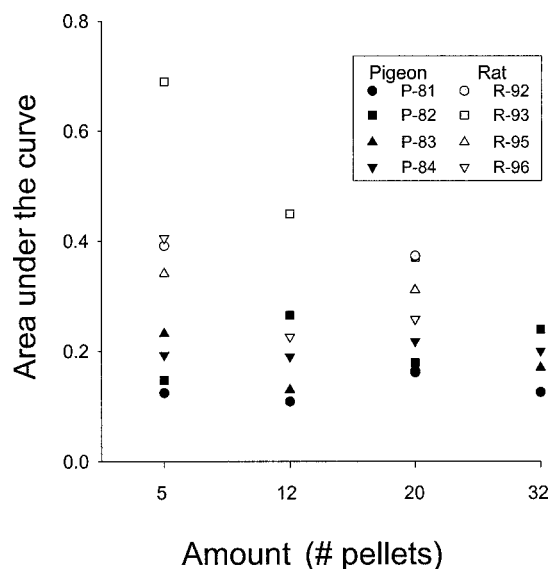


Fig. 6. Estimates of the area under the discounting curve for each subject in each amount condition. Steeper discounting is indicated by smaller areas under the curve.

in which pigeons responded for delayed food (e.g., Mazur, 2000) and rats responded for delayed water (Richards et al., 1997). Thus the present data obtained using similar rewards and procedures with both species represent an important confirmation of Mazur's hypothesis. Moreover, as Mazur pointed out, pigeons and rats discount delayed rewards orders of magnitude more steeply than humans do.

As indicated previously, the pigeons were maintained at 80 to 85% of their free-feeding weights, and the rats were provided 1 hr of access to food immediately after each experimental session. Although the feeding regimen for the rats differed from that of the pigeons in order to allow for growth, it had similar effects. One month following the beginning of the experiment proper, the rats' weights ranged from 79 to 86% of their preexperimental, free-feeding weights. Thus, although the feeding regimens were different for the pigeons and rats, this appears unlikely to explain the apparent species difference in discounting rate.

Comparison of the hyperbola (Equation 1) with a hyperbola-like discounting function (Equation 2, in which the denominator is raised to a power, s) revealed that the simple

hyperbola sufficed to provide an accurate description in almost all cases. Similarly, inspection of the Richards et al. (1997) data for temporal discounting of delayed water rewards in rats reveals no systematic deviations from the simple hyperbola. This finding regarding the form of the temporal discounting function in nonhuman animals appears to differ from the results obtained with humans for whom Equation 2, with an s less than 1.0, often provides a significantly better fit than Equation 1 (e.g., Myerson & Green, 1995; Simpson & Vuchinich, 2000).

As Mazur (2000) pointed out, however, the data from his study of temporal discounting in pigeons reveal systematic underprediction by Equation 1 at the longer delays, suggesting that Equation 2 might provide a better fit. To evaluate this possibility, we refit the data provided in Mazur's Table 2. Notably, the value of the exponent, s , was significantly less than 1.0 in 3 of the pigeons and marginally so for the 4th pigeon (Bird 6). Similarly, in the two cases in the present study in which s differed significantly from 1.0, the estimated value of the s -parameter was also less than 1.0. Thus, in nonhuman animals as in humans, there appear to be cases in which an exponent is required to describe temporal discounting

functions accurately, and in those cases, the value of the exponent is less than 1.0.

An important finding of the present study was that in contrast to humans (e.g., Green et al., 1997), determination of temporal discounting functions in individual pigeons and rats using an adjusting-amount procedure failed to reveal a magnitude effect in either species. That is, rate of discounting (as measured by both the k -parameter and the area under the curve) did not vary systematically as a function of the amount of the delayed food reward. The present results are consistent with those reported for rats with water rewards (Richards et al., 1997), suggesting that the lack of a magnitude effect in rats is not peculiar to one type of reinforcer.

Thus there are both similarities and differences among the discounting of rats, pigeons, and people. On the one hand, the same forms of discounting function describe behavior by all three species; on the other hand, humans show much shallower discounting than either the rats or the pigeons, and, in contrast to the latter two species, humans discount smaller rewards more steeply than larger rewards. With respect to the apparent species difference in steepness of discounting, it is possible that these differences reflect behavioral adaptations to different niches. A related idea has been suggested by Tobin and Logue (1994) who pointed out that species differences in choice behavior could reflect differences in metabolic rate, with smaller species (who have higher metabolic rates) showing less self-control, perhaps reflecting steeper discounting. It is also possible that in the case of humans, the higher value of future rewards reflects an effect of language, although based on a study showing self-control in macaques, Tobin, Logue, Chelonis, Ackerman, and May (1996) suggest that language may not be the crucial factor.

With respect to the lack of a magnitude effect in rats and pigeons, it might be argued that the range of amounts studied was not as great as is generally used with humans. For the pigeons in the present study, the range of amounts studied was more than sixfold (from 5 to 32 pellets), and for rats the range was fourfold (from 5 to 20 pellets). In Richards et al. (1997), the range of water amounts studied with rats was only twofold (100 to 200 μ l). In contrast, the range of delayed reward

amounts examined in humans has often been much greater. To take an extreme example, Raineri and Rachlin (1993) studied amounts of hypothetical monetary rewards ranging from \$100 to \$1 million. Importantly, however, differences in discounting rate have been obtained in humans with much smaller differences in amount (e.g., \$10 vs. \$20; Kirby, 1997) that are more comparable to the range of amounts examined in pigeons and rats.

Another possible explanation for the apparent lack of a magnitude effect in pigeons and rats relies on the observation that in humans, increasing the amount of the delayed reward affects discounting rate up to a certain point beyond which further increases in amount have little or no effect (Green et al., 1997; Green, Myerson, & Ostaszewski, 1999). Thus it is possible that for food-deprived rats and pigeons, the magnitude of reinforcement associated with five pellets is already sufficiently large that further increases in the number of pellets have no effect on discounting rate. Although we used the smallest commercially available pellets, in a future study one might use even smaller food pellets in order to test whether reward amount affects discounting rate in pigeons and rats.

A third possibility is that food and water reinforcers are in a special category because they are essential to survival. Most studies of discounting in humans in which magnitude effects have been reported have used hypothetical monetary rewards, although magnitude effects in humans have also been reported for real monetary rewards (e.g., Kirby, 1997) as well as for hypothetical nonmonetary rewards (e.g., Raineri & Rachlin, 1993). Thus the effects of amount of reward on discounting rate have received broad support in human studies. Nevertheless, no studies have examined the effects of amount of food and water reinforcers on discounting in humans and the present findings highlight the need for such research using real rewards. An alternative approach to the issue might be to examine the discounting of nonessential reinforcers in rats or pigeons in order to determine whether magnitude effects are observed under such circumstances (for an approach to studying choice in pigeons using delayed token reinforcers, see Hackenberg & Vaidya, 2003; Jackson & Hackenberg, 1996).

There remains the possibility that the observed lack of a magnitude effect in pigeons and rats represents a true species difference from humans. If this interpretation were to prove correct, then it would raise the question as to why humans are different from other animals in this regard. The role of language in human behavior is, of course, always a possible explanation for such species differences. For example, in order to explain the magnitude effect, Loewenstein and Thaler (1989) proposed that people maintain two separate mental accounts, one for small, immediately consumable amounts (“windfalls”) and one for large amounts that are assigned to a mental savings account. These two mental accounts are assumed to be associated with separate discounting rates. Such an explanation, which relies on distinct linguistic categories, would predict that one would not observe a magnitude effect in nonverbal organisms.

Although the present results are consistent with this prediction, there are two lines of evidence that call into question the mental accounts explanation of magnitude effects in humans. First, multiple mental accounts, rather than the two proposed by Loewenstein and Thaler (1989), would be required to explain the fact that discounting rates decrease continuously, at least up to a point, as amount of reward increases (Green et al., 1997; Green et al., 1999). Second, magnitude effects have been reported for delayed non-monetary outcomes such as health (Chapman, 1996) and vacation time (Raineri & Rachlin, 1993) for which separate mental accounts for small and large amounts seem unlikely.

The magnitude effect in humans is important in part because it represents an anomaly from the standpoint of normative economic theory. The apparent species difference in magnitude effects may not be the only instance in which human behavior fails to conform to economic theory whereas the behavior of nonhuman animals does conform. It is well established that humans show a “sunk cost” effect (i.e., the tendency to consider the effort, time, or money already invested in a behavioral strategy, rather than considering only future costs and benefits as would be “rational”). Arkes and Ayton (1999) argued that, in contrast, nonhuman animals do not

show this tendency because it depends on overgeneralization of an abstract rule (“don’t waste”) that animals do not possess. It is possible that the magnitude effect in humans (which is also “irrational” by normative economic standards) also represents rule-governed behavior, but evaluation of this possibility waits upon specific, testable hypotheses as to what such a rule might be.

Finally, despite the observed differences in discounting behavior among humans, pigeons, and rats, we would stress the strong similarities as exemplified by the finding that in each case, a similar mathematical function provides an excellent description of the effect of delay on the present (subjective) value of a future reward. A key question for future research is whether the similarity in discounting functions reflects a similarity in the underlying process, albeit a process that may be modulated by amount in some species but not in others.

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