A TEMPORAL LIMIT ON THE EFFECT OF FUTURE FOOD ON CURRENT PERFORMANCE IN AN ANALOGUE OF FORAGING AND WELFARE

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Rats obtained access to food twice each 24-hour period. The first session was a work session in which food was available on a progressive-ratio schedule. During the second session, which occurred between 1 and 23 hours after the work session, food was freely available up to a fixed total intake each 24 hours. The situation resembled elements of several real world circumstances, including the choice between continuing to forage in a rapidly depleting patch and waiting for a better patch, and between working now and receiving a guaranteed income later. The purpose of the experiment was to explore the time period over which future access to reward could affect current responding. Contrary to what might be expected from recent theorizing, anticipation of future food delayed by an hour or more after the start of the work session had no effect on current performance. Food intake was high and constant during work sessions except for a prefeeding effect that occurred when the free session closely preceded the next day's work session. Also, an increase in the difficulty of the work schedule increased the amount of work and the maximum price paid for food as if the work session were the only time food was available. The results indicate the importance of considering temporal limits in theories that require animals to integrate input over time to determine the allocation of resources among alternatives.

Key words: optimality theory, behavior regulation, welfare, foraging, rats

A problem of general theoretical and practical interest in behavior theory is how organisms allocate resources among present and future opportunities for access to important commodities. In economics, the choice is between buying now or later; in foraging, between searching here or elsewhere, now or later; in welfare, between working now or taking a welfare check later; and in "self-control" research, between taking a small reward immediately or the larger reward later. A key aspect of this problem is the evaluation of future and present rewards. In operant research, comparisons are typically made between two mutually exclusive response alternatives that differ in value. This value is determined by a discounting function that is presumed to decrease as a function of the temporal delay of the reward and/or the effort required to obtain it. For example, animals in self-control paradigms take smaller immediate rewards (Rach-

lin & Green, 1972), and animals in concurrent chain schedules choose shorter total links (Fantino, 1977), both presumably because of the discounting effect of temporal delay.

In contrast, recent work in economics, foraging, and behavioral regulation has viewed choice within the context of the overall regulation of time, energy, behavioral output, or income. Instead of asking which of two mutually exclusive response alternatives an animal might choose, researchers are concerned with how repeated choices of both, either, or neither will contribute to overall optimization or regulation of behavior. Thus, in foraging, animals enter and leave patches, pick dietary items, and time activity cycles not on the basis of any absolute value of the rewards, but on how total behavior will optimize net-energy gain (Belovsky, 1978; Krebs, 1978; Pyke, Pulliam, & Charnov, 1977; Schoener, 1971). In economics (Rachlin, Battalio, Kagel, & Green, 1981) and behavior regulation (Hanson & Timberlake, 1983; Rachlin & Burkhard, 1978; Staddon, 1979; Timberlake, 1980, in press), responding is presumed to decrease the distance from overall bliss points or behavioral baselines.

It is not my intent here to determine which

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approach or combination of approaches is most correct, but to explore the mutual dependence of their predictions on the time period over which future rewards affect current behavior. Stated another way, I am concerned with the time period over which subjects integrate input in making choices on how to distribute their resources (e.g., Rachlin, 1982). Based on classic delay-of-reward gradients (e.g., Grice, 1948), it would seem that the time period over which future rewards affect behavior is measured in seconds. However, the behavioral contrast literature suggests an effect of alternative rewards ranging up to 5 or 6 min (e.g., McSweeney, 1982). The data of Hodos and Trumbule (1967) indicate that chimpanzees may evaluate alternative rewards perfectly over a period of approximately 15 min. Measures of the anticipatory activities of animals on 24-hr feeding schedules suggest an effect of future rewards extending into the hour range (e.g., Bolles, 1967; Boulos & Terman, 1980), a time period also indicated in work on foraging in nectar-feeding birds (Kamil, 1978). Finally, some animals in the wild show apparent anticipation of food scarcity in winter by a factor of days and even months (Kayser, 1965). Similar abilities are attributed to human welfare recipients who are presumed to optimize the trade-off between total income and leisure over time periods ranging from months to a year (Rachlin et al., 1981).

The present research explored the time interval over which future rewards affect current rewarded performance. Rats were confronted with the alternative of working on a progressive-ratio schedule of food delivery during a daily 1-hr work session, and receiving any unearned part of a guaranteed daily intake in a subsequent free session. Thus, the animal could work for most, none, or an intermediate amount of its fixed daily intake, and receive the remainder free at a later time. This paradigm is analogous in many respects to the choice in foraging between exploiting a rapidly depleting patch and waiting for a much more generous one, or in welfare between working at increasingly low wages versus receiving a welfare check. The fixed total food intake eliminated changes in over-all levels of deprivation as a determinant of choice, and prevented any over-all (daily) advantage to the animal of responding more in the work session. The progressive-ratio schedule imitated a rap-

idly depleting patch; the quitting point established the maximum price paid for the food. That the animal stopped responding while still hungry could be viewed as daily extinction which decreased any contribution of habit to responding in the work session.

The major independent variable was the delay time between the beginning of the work session and the beginning of the free session; it was varied from 1 to 23 hr. If a temporal discounting function exists in this time range, then total work should vary directly with the delay between the work and free sessions. As the delay time becomes longer, the value of the free food will be discounted more and have less effect on bar pressing in the work session. The progressive-ratio schedule is important in this prediction because the increasing ratio requirement ensures that the value of a current pellet will fall below any positive value of future free pellets. A second independent variable was the severity of the progressive ratio (the rate at which it increased). Total work should decrease as the severity of the schedule goes up, because the increased work should devalue the current reward at a greater rate.

A simple overall optimization view rarely specifies the time period of integration, but many investigators have presumed it to be in the day range (e.g., Belovsky, 1978; Schoener, 1971). In the present case, if the animal is able to integrate the information that there exists an alternative to the work session, very little responding should occur in the work session because neither the total intake nor the time to obtain it can be changed by any distribution of bar pressing. Thus, to maximize its benefit per cost, the animal should press the bar very little during the work period no matter what the delay interval. Also, as the severity of the progressive-ratio schedule is increased, Char-nov's (1976) marginal-value theorem predicts that the animal should always quit the work "patch" at approximately the same price for food.

On the other hand, if the animal is insensitive to the reliable occurrence of a subsequent free session, the optimization view predicts that animals should perform maximally under the work session. Behavior-regulation theories further predict that as the severity of the progressive-ratio schedule is increased, animals will quit the work patch at higher prices as they approach baseline levels of re-

ward under increasing challenge (e.g., Hanson & Timberlake, 1983; Staddon, 1979; Timberlake, 1980).

METHOD

Subjects

The subjects were 2 male Sprague-Dawley rats, 110 days of age at the beginning of the experiment. The rats were housed singly and were completely deprived of both food and water outside the experimental chamber.

Apparatus

The apparatus was a 20.3 by 30.5 by 20.3-cm chamber with a grid floor, two bars, and two cue lights. The bars were retractable and each session began when they were inserted and the appropriate cue light was turned on. Food and water receptacles were located between the two bars. Food was presented in the form of 97-mg Noyes pellets, and water was presented in the form of 0.02-ml drops. The presence of food was detected by an infrared receptor circuit across the bottom of the feeder, and the presence of water was detected by a continuity circuit between a small stainless steel cup and the metal delivery tube. Thus, it was possible to deliver a packet of food or water each time the animal removed one. This technique was used in the initial baseline period and subsequently in the free sessions.

Procedure

The rats initially received 40 daily hour-long sessions during which food and water were freely available in the chamber; these sessions were used to establish their baseline levels of intake—162 pellets for Subjects 17 and 150 pellets for Subject 19. After bar pressing was shaped with food reinforcement, the rats were placed on a series of daily contingency conditions during which food was available during a 1-hr work session under a progressive-ratio schedule and during a subsequent free session in which food was freely available until the animal had obtained its established daily intake or 1 hr had passed. Only very rarely did the animal fail to reach its regular daily intake during the free session. Water was available under both the work and the free-food sessions. During the work session, a green light over the bar farthest from the door was lit, and presses on that bar produced food on the appropriate

ratio. During the free-food session, a red light over the bar closest to the door was lit, and presses on either bar had no effect on obtaining food.

Three progressive-ratio schedules were used, providing for different levels of difficulty in obtaining food: PR1-1 in which the step size was one and the dwell number at any particular ratio was one, PR1-2 in which the step size was one and the dwell number was 2, and PR1-4 in which the step size was one and the dwell number was 4. The dwell number was the number of times an animal remained at a given schedule value prior to moving to the next higher value. All animals were run first on a PR1-2 schedule, followed by a PR1-4 schedule and a PR1-1 schedule. Under the PR1-2 and PR1-1 schedules, free sessions were provided either 1, 2, 4, 7, 10, 16, 20, or 23 hr following the beginning of the work session. Under the PR1-4 schedule, animals received only a single delay interval of 1 or 2 hr. Animal 17 did not receive all delays on the PR1-1 schedule because of illness. The animals continued on each temporal-delay condition until stable behavior was recorded, a minimum of 10 days and a maximum of 24. Stable behavior was defined by apparent visual stability of performance and no evidence of a trend between the mean of the first and last three days of the last group of six. The conditions of temporal delay were presented in random order for each animal, except that both received delays of 1, 2, 4, and 23 hr before any of the others. Following the final condition, Subject 19 was run on a PR1-2 schedule for 8 days with no free session, and, thus, no guaranteed amount of food.

RESULTS

The weights of the animals are plotted in Figure 1 as 5-day medians at asymptote in each condition. They show a high degree of reliability across different delay times between the work and free-food session and across the varying schedule requirements. Apparently preserving total daily food intake at 162 pellets for Subject 17 and 150 pellets for Subject 19 was sufficient to maintain a constant weight across variation in temporal patterns of intake and in the severity of the schedule during the work session.

Figure 2 shows asymptotic median intake of food during the work session as a function of

Fig. 1. Median weight in grams before the work session (at 5-day asymptotes for each condition) plotted over the delay time between the start of the work and free-food sessions (1 to 23 hr) by severity of the progressive-ratio schedule. All schedules had a step size of one and dwell frequencies of 4 (easy, PR1-4), 2 (medium, PR1-2), and 1 (hard, PR1-1).

the delay time between the work and free sessions, and as a function of the severity of the schedule. It is clear that in most cases the animals worked for a considerable number of pellets during the work session despite the fact that pellets were freely available in the subsequent free session. In fact, when no free session was allowed, Subject 19 took only six more pellets on a PR1-2 schedule than when the free session was allowed. Such a small difference in intake easily could have been due to the markedly greater body-weight loss when the free session was not available.

The results in Figure 2 show little effect of the delay time between the work and free sessions. Only in cases that amounted to prefeeding with respect to the next day's work session was there a consistent change in the number of pellets taken during the work session (the 23-hr delay time for both subjects on the medium and hard schedules, and the 16- and 20-hr delay times for Subject 19 on the hard schedule). Finally, it can be seen that the in-

Table 1

Work performed (bar presses) and average and highest prices paid (bar presses per pellet) on easy, medium, and hard progressive-ratio schedules (PR1-4, PR1-2, PR1-1).

	Progressive-Ratio Schedule		
	Easy	Medium	Hard
Subject 17			
Total Work (BP)	684	812	1326
Avg. Price (BP/Pel)	10	14	26
Max. Price (BP/Pel)	18	28	51
Subject 19			
Total Work (BP)	669	963	1129
Avg. Price (BP/Pel)	9	16	24
Max. Price (BP/Pel)	17	30	47

take of food varied inversely with the severity of the schedule. The maximum intake occurred during the easiest schedule (PR1-4), and the least intake occurred during the most difficult schedule (PR1-1).

Table 1 shows the total work performed and

Fig. 2. Median pellets eaten during the work session (at 5-day asymptotes for each condition) plotted over the delay time between the start of the work and free-food sessions (1 to 23 hr) by severity of the progressive-ratio schedule. All schedules had a step size of one and dwell frequencies of 4 (easy, PR1-4), 2 (medium, PR1-2), and 1 (hard, PR1-1)

the maximum price paid over the delay time (either 1 or 2 hr) at which each animal received all three levels of schedule difficulty. It can be seen that neither the total amount of work, the highest price paid for a food item, nor the average price paid remained constant. All increased systematically as a function of schedule difficulty. However, as shown in Figure 2, these increases were not sufficient to maintain constant intake during the work sessions.

DISCUSSION

The data clearly show, at least with respect to the inhibiting of instrumental responding, that rats were completely unable to bridge delay times of 1 hr in anticipating future reward. There was no measurable effect of free future food on current responding. Instead the rats appeared to treat the work session as an entirely self-contained world, increasing their bar pressing with the severity of the progressive-ratio schedule in partial compensation for re-

duced access to food (Hogan & Roper, 1978; Staddon, 1979; Timberlake, 1980), rather than maintaining a constant maximum price, as called for by one form of optimal foraging analysis (Charnov, 1976). Similar compensatory reactions to changes in schedule difficulty were reported by Hodos and Kalman (1963) using more severe progressive-ratio schedules and typical postsession feeding. In the present case it might be argued that Rat 19 showed some inhibitory effects of anticipation of future food in that when free feeding was not offered on the intermediate-difficulty schedule, its intake increased by six pellets. However, this relatively small increase could be attributed readily to the marked drop in body weight that accompanied removal of the free feeding time. Surprisingly, despite the weight loss the increase in intake was less than occurred when the easy schedule was imposed and the free feeding session was allowed. Apparently in this situation, price is a very potent determinant of intake.

These results suggest that discounting functions for the value of future rewards do not exist in the hour range, and call into question the ability of rats to forage optimally on the basis of integrating input over time intervals of an hour or more. Since considerable data have indicated that animals regulate daily intake of food in ways that maintain body weight (e.g., Zeigler, 1976), anticipate feeding times by several hours or more (e.g., Bolles, 1967), and react to future seasonal deficits by increased intake (e.g., Kayser, 1965), mechanisms must exist for bridging such periods of time. However, such mechanisms do not seem to be accessible to rats in the present circumstances. The results suggest that predictions of optimality models that do not carefully consider the time period over which alternatives can be integrated and the mechanism of integration should be viewed with caution (e.g., Krebs, 1978; Rachlin et al., 1981). The "time horizon" problem in foraging is apparently a critical one (Lea, 1981).

The data have similar ramifications for theories that presume that animals regulate or maintain output levels or consumption over time (e.g., Allison, 1976; Lea, 1980; Staddon, 1979; Timberlake, 1980). Responding within the work session followed the predictions of a behavior-regulation approach by showing an increase in bar pressing and a decrease in pellets obtained with initial increases in the severity of the schedule. However, the animals apparently failed to include the free and work sessions within the same time frame. It seems that animals do not directly maintain (or conserve) output of bar pressing and eating over time periods of an hour or more. Apparently any longer term constancies that occur must be based on maintaining output over smaller time units.

However, several mitigating circumstances should be considered before completely accepting the inability of future access to reward to affect current performance. First, the present circumstances differ from natural foraging situations in that the animal cannot leave the less dense patch while waiting for the more dense patch, and so it is exposed continuously to the instigating conditions in the less dense patch. Perhaps if allowed to leave, the animal would stop working at an earlier point. It may be worth considering that rats sometimes work for food even in the presence of free food (e.g.,

Osborne, 1977), though seemingly not as much as if the free food were not present. It might also be of interest to allow the animal to "commit" itself to the free rather than the work session at a time considerably preceding accessibility. Such procedures have allowed organisms to choose later larger rewards in the "self-control" paradigm (Rachlin & Green, 1972). Second, it could be argued that rats have species-typical reactions to food that produce relatively automatic intake of any food encountered. Though something like this is probably part of the story, it is not in accord with data on optimal foraging obtained with diet selection in birds (e.g., Krebs, 1978), and it would still seem reasonable for the rat to show at least a small effect of future reward occurring within the next few hours.

The present experimental design meant that delay from a work session to the next free session varied inversely with time to the work session from the *previous* free session. This opens the possibility that the relatively constant performance in the work session was not due to the absence of an effect of anticipation of free food, but was due to the canceling of the excitatory effects of deprivation (time since last feeding) and the inhibitory effects of anticipating the next free feeding. However, this model requires several assumptions that make it unattractive. First, the model requires that changes in the inhibitory effects of anticipation and the excitatory effects of deprivation must be perfect mirror images of each other over nearly 24 hr, except for the period of 0 hours of deprivation, and 3 and 7 hours of deprivation for Subject 19 working under the hard schedule. Second, anticipation of feeding is presumed to have only inhibitory effects on instrumental responding, an unlikely restriction (Boulos & Terman, 1980). Any excitatory effects of anticipation will add to the effects of deprivation rather than canceling them. Third, removing the free feeding session completely (and thus minimizing the inhibitory effects of anticipation) increased pellet intake in the work session by only six. This means that the maximum change in the inhibitory effect of anticipation of free feeding across 23 hr was only worth six pellets, hardly enough to counteract the change in feeding tendency as deprivation varied from 1 to 23 hr. Finally, this approach has no explanation for the variation in intake in the work session as a func-

tion of schedule changes. Such variation occurred in the absence of changes in deprivation or presumed anticipation.

Viewed as an analogue of the behavior of welfare recipients, these data are of interest because a guaranteed adequate daily food intake did not prevent the animals from working, and working quite hard. Only when food was provided shortly before the work session was work reduced. These results indicate that the reason most animal-based studies of "welfare" have shown that free income reduces work is that it was presented just before or during the opportunity to work (e.g., Allison & Boulter, 1982; Green, Kagel, & Battalio, 1982). Drawing any strong analogy with current welfare practices in our society is problematic because humans time-bind more effectively than animals in anticipating future events, and social customs and relations markedly influence behavior. However, to the extent that humans and rats share motivational tendencies, any welfare procedure providing a large segment of guaranteed income just before or during work opportunities should produce less work than income following work that compensates for any unearned amount. Thus, minimum welfare "payments" are likely to occur when an opportunity to work for immediate income is provided prior to receiving any subsequent guaranteed income. Certainly the subjects in this experiment worked rather than waited when in the presence of work cues (see also Singh, 1970).

The data also bear on the distinction between open and closed economies (Hursh, 1978; Schwartz & Lacey, 1982). The present paradigm was presumably a form of open economy in that the subject worked for a portion of its daily intake during a work session, and then received a compensating access to free food at a later point. Thus, the animals should have responded to increases in the severity of the schedule by decreases in work (e.g., Hursh, 1978; see also Schwartz & Lacey, 1982, p. 123). However, they clearly responded to increasing challenge by increases in output, as did the animals of Hodos and Kalman (1963) in a similar situation. Because the effects of an open economy are presumed to be based on anticipation of later food (Schwartz & Lacey, 1982) and the present results show no effect of future feeding within an hour, the distinction between open and closed economies may be ques-

tioned. Based on these data, it seems plausible that the behavioral differences typically cited for open and closed economies are based on differences in the severity of the schedule rather than on the type of feeding regime (Timberlake & Peden, 1977).

In short, these data clearly show empirical limitations on the rat's ability to modify its behavior on the basis of food sources removed from the present by 1 hr. This suggests that at least some decisions leading to maintaining daily food intake are based on mechanisms regulating local intake, not on an overall evaluation of behavior and pay-offs. If rats have any generally accessible ability to evaluate alternatives and inhibit less efficient behavior, it must work over smaller time intervals, or in different circumstances. The only data I am aware of that show flexible integration of future and current rewards are those of Hodos and Trumbule (1967) on chimpanzees, and that ability appears to deteriorate after approximately a 15-min interval. Such results suggest that current research should focus more on mechanisms of temporal integration and a little less on general mathematical models and techniques that are available to the researcher but not to the subject.

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