TIME HORIZONS IN RATS: THE EFFECT OF OPERANT CONTROL OF ACCESS TO FUTURE FOOD

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The primary goal of this experiment was to determine whether the addition of an operant requirement for access to a less costly (continuous reinforcement) patch of future food increased the time horizon over which that future patch decreased intake in a currently available depleting (progressive-ratio) patch. Three groups of 4 rats were tested. Each member of the earned-time group was required to cumulate a fixed-time outside the progressive-ratio patch to obtain access to food in the less costly patch; the fixed-time requirement ranged from 2 to 64 min. Rats in the matched-time group received response-independent access to less costly food at the average delay shown by the earned-time group. Rats in the matched-time no-food group were removed from the chamber at the same average delay without receiving access to less costly food. Two of the earned-time rats showed an increased time horizon relative to that shown by the matched-time rats (approaching 40 min for 1 rat). The other 2 earned-time rats markedly increased instrumental responding but showed suppression of intake only when food was less than 20 min away. The matched-time group showed less suppression of intake over a similar range of delay intervals. Surprisingly, the matched-time no-food animals also showed suppression of intake concentrated at the end of the session, possibly reflecting the receipt of their entire daily ration 30 min after the session. The potential importance of time horizons to the foraging process is clear, but experimenters are still working out paradigms for investigation of these horizons.

Key words: time horizons, operant control, anticipation of food, progressive-ratio schedule, patches, lever press, rats

In foraging for food, animals distribute their behavior among a variety of potential resources. The dominant biological view is that this distribution of foraging in a known environment will be close to optimal in the sense of producing the greatest net benefit per unit time (Charnov, 1976; Pyke, Pulliam & Charnov, 1977; Schoener, 1971). Recently, there has been increasing concern with the role of local mechanisms (rules of thumb) in determining foraging behavior (Fantino & Abarca, 1985; Krebs & McCleery, 1984; Stephens & Krebs, 1986), but few have considered the potential relevance of the animal's time horizon, that period of time over which current responding can be affected by an alternative food source. Instead much foraging research seems to assume that the extent of the time horizon for evaluating alternative food sources is at least several hours and perhaps longer than a

day for some species and commodities (e.g., Belovsky, 1978; Kamil, 1978).

Despite obvious potential relevance for mechanisms and models of foraging (Kamil & Roitblat, 1985; Lea, 1981), time horizons have received only little direct investigation. The most common experimental method has been to define the time horizon as the length of the experimental session or the foraging bout (e.g., Dow & Lea, 1987; Kacelnik, 1979; see also Lucas, 1987) and to determine whether session length changes the distribution of responding. A problem with this method is that it typically does not establish the temporal limits over which future food can affect current responding, showing only differences between the effects of two session lengths. A further problem is that the effects of session length often are confounded with differences in the frequency of reward for a response. Thus, the effects of changes in session length on choice may reflect previous differences in reward frequency for the alternatives (Shettleworth & Plowright, in press).

An alternative design has been to test whether animals can choose optimally between alternatives that pit differences in immediate

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rate of food availability against opposite differences in overall rate of food availability. Nonoptimal behavior is taken as evidence that the time horizon of the animal is shorter than the period necessary to estimate accurately the overall rates of reward. For example, Mazur (1981) showed that pigeons most frequently chose a schedule producing a higher initial rate of reward but a lower overall rate. This finding is consistent with the self-control literature, which also provides examples of animals behaving suboptimally by choosing a smaller closer reward rather than a larger more distant reward (Ainslie, 1974; Logue, *in press*; Rachlin & Green, 1972).

A problem with this method is that it also provides little evidence that animals can act optimally under the conditions tested. The choice response seems based less on time horizons than on powerful response-evoking properties of local behavior-control mechanisms that interfere with effects of alternative responses over longer intervals (Timberlake, *in press*). In support of this view, as the choice of alternatives is made more distant from access to reward, animals begin to respond more to the overall rate of reward (Rachlin & Green, 1972; see Logue, *in press*, for a summary).

A preferable procedure for testing time horizons attempts to bracket the potential horizon interval by manipulating the time interval between two feeding "patches." Given that the first patch is less attractive than the second, an inverse relation between responding in the first patch and the delay to the second patch would be expected. When the second patch is close, the animal should show relatively little first-patch responding. As the second patch is delayed, the animal should increase responding in the first patch to the point that the presence or absence of the second patch is irrelevant. That shorter intervals suppress first-patch responding shows that the testing situation is sensitive to the effects of future food. That longer delays produce no effect shows a temporal threshold on the effects of future food in the test circumstances.

In experiments based on this design, Timberlake (1984) and Timberlake, Gawley, and Lucas (1987) examined the responding of rats in a depleting patch (food was available on a progressive-ratio—PR—schedule) as a function of the length of delay to future, less costly food. The results indicated a distinction be-

tween the effects of future food in increasing responding directed to its location (anticipation) and the effects of future food in decreasing responding in the depleting patch (suppression). Although rats showed some anticipatory responding when future food was delayed by more than an hour from the onset of the experimental session, they decreased feeding in the PR patch only when the delay to future food was 16 min or less. Delays of 32 min or longer produced no decrease in current intake. Thus, in these circumstances rats had a time horizon for the effects of future food on current responding on the order of 16 min.

A time horizon of 16 min for a rat foraging for food appears surprisingly short for most models of how animals forage optimally among alternative resources over a 24-hr period. However, our test may have underestimated the potential time horizon for several reasons. First, the procedure resembled a Pavlovian conditioning paradigm in that food was made available in the less costly patch after a fixed delay, no matter what the rat did. In natural foraging situations there is usually an operant component such that animals can increase the probability of obtaining access to a less costly food by leaving a current depleting patch and searching elsewhere (Charnov, 1976). Because there was no such operant in the present situation, the effects of future food on current responding may have been weaker and based primarily on the Pavlovian conditioning of anticipatory responses.

Compounding any weakness of effect was the continued presence of cues associated with the effective operant of lever pressing for food in the depleting patch. Given a hungry rat and only one operant response that increased the probability of food, the rats may have lever pressed for food in the depleting patch with little regard for overall net benefit per unit time. Making available an alternative operant response leading to less expensive food should increase the effective time horizon in both the above cases.

Second, Timberlake *et al.* (1987) noted that suppression of intake in the PR patch may have been the result of competition between continuing to forage in the depleting patch and anticipatory activity in the continuous reinforcement (CRF) patch. Suppression occurred only when such competition was possible, that

is, when the animal was likely to be engaged in an eating bout of sufficient intensity that anticipatory entries to the CRF patch could only occur by taking time away from working for food in the PR patch. Adding an operant response leading to an alternative food source should increase the potential for competition with lever pressing for food in the depleting patch, especially at larger response requirements for access to the CRF patch.

Finally, in Timberlake et al. (1987) daily intake was not strictly limited. It therefore was possible for the rats to increase slightly their total daily intake by continuing to lever press in the PR patch until the CRF patch became available. Also, in the absence of limited intake, the rats may not have been sufficiently deprived to produce suppression effects at longer intervals. Both of these possibilities were addressed in the present experiment by maintaining the rats at 85% of their free-feeding weights thus allowing no overall advantage in intake for continuing to lever press in the depleting patch.

The present study compared the behavior of three groups of rats to determine whether providing an instrumental response for access to food in a less costly (CRF) patch would increase the time horizon over which suppression of responding in a depleting (progressive-ratio) patch would occur. Each rat in Group ET (earned-time) was required to cumulate a period of time outside the depleting patch before food was made available in the CRF patch. These time periods ranged successively from 2 min to a maximum of 64 min. We used an increasing series of intervals to provide maximum opportunity for the animal to learn and perform the response.

We chose a depleting schedule because depletion of resources in a patch during foraging is a circumstance that occurs in many natural settings and because the depleting schedule was used by Timberlake et al. (1987) in establishing the 16-min time horizon we were investigating. Further, we felt that an ascending ratio schedule would provide a more sensitive and continuous test of the effects of future food than would a single fixed-ratio schedule.

We also chose the operant response of "time outside the depleting patch" to mimic a natural circumstance, one in which an animal leaves a depleting patch when richer ones are potentially available (Charnov, 1976). We felt that

requiring a more focused "changeover" response, like pressing a lever at a particular location, would prevent comparison of responding with the matched groups, which did not have such a changeover response. In contrast, the animal's location can be measured and compared for all groups.

Animals in Group MT (matched-time) received the same average delay to CRF food produced by Group ET but in the absence of any instrumental requirement. In essence this group was a replication of Timberlake et al. (1987). Animals in Group MTNF (matched-time, no-food) received the same period of access to the depleting patch but no access to food in the CRF patch. Behavior of this group was intended to reveal any effects of the different session lengths in the absence of a following CRF patch.

Based on the results of Timberlake et al. (1987), we expected that intake in the PR patch would decrease as an inverse function of the delay to CRF food for both Groups ET and MT. If the limited time horizon previously reported was primarily due to the absence of an alternative operant response leading to food, the rats in Group ET should show suppression of responding in the depleting patch over longer intervals than Group MT. If the previously reported time horizon was affected by a slight increase in total intake by continued responding in the depleting patch, or by lack of sufficient deprivation, both Groups ET and MT should have longer horizons in the present study. Finally, we wanted to determine whether suppression of intake in the depleting patch occurred across the entire interval (as it tended to for subjects in Timberlake et al., 1987) or whether it began part way through the interval preceding access to the less costly food.

METHOD

Subjects

The subjects were 15 female Sprague-Dawley albino rats bred in a local colony at Indiana University. They were housed singly in metal cages under a 12:12 hr light/dark cycle and maintained at 85% of their free-feeding body weights by daily feeding. Three of the rats developed a respiratory ailment during the course of the experiment; their data are not reported.

Apparatus

The apparatus consisted of four sheet metal boxes, 50 by 35 by 38 cm, with a Plexiglas front and top. The boxes are described more completely in Timberlake *et al.* (1987). Each box contained two retractable levers on the back wall separated by a T-shaped partition so the levers were a travel distance of 80 cm apart. The partition divided the box into two equal patches connected by a "tunnel" formed by the top bar of the T and the front of the apparatus. A small segment of the stem of the partition moved to allow access from either side to a food tray located between the two levers. Bio Serv 94-mg dustless pellets were delivered to the food tray using a Waltke Feeder. A green jewel light (24-V DC) was located above the left bar, and a red jewel light was located above the right bar.

Three weight-sensing floor panels determined the location of the subject in the box. The feeder panel (10 by 12 cm) was centered in front of the food receptacle. Two side panels (28 by 12 cm) were centered along the two side walls. Because of the top bar of the T, the animals could not leave or enter a patch without crossing one of the side panels. The apparatus was controlled by an IBM-PC® and solid state interface located in an adjacent room. Programmed contingencies and data collection were managed at a 0.1-s resolution using Conman Contingency Management Software® (Spyder Systems, Bloomington, Indiana).

Procedure

Subjects were trained to lever press in 2 days during which the subject received half of its pellets (range, 20 to 34) on one side of the apparatus and half of its pellets on the other side. The side producing the first 25 pellets was alternated and was signaled by a light above the active bar. During the experiment rats continued to have free access to both sides of the apparatus; one side was designated the current depleting or PR patch, the other was the future or CRF patch. The location of a patch was always the same for a particular animal but was counterbalanced between animals.

Each session began with the insertion of both levers, but only the PR lever was functional (indicated by illumination of the light over the lever). The PR schedule was dwell

1-step 1, meaning that the required number of lever presses increased by one each time a pellet was earned (Timberlake, 1984). For the 4 rats in the experimental group (Group ET—earned-time), the CRF food became available for 6 min (indicated by illumination of the light above the CRF level) after 2, 4, 8, 16, 32, or 64 min of cumulated time spent *not* actively foraging in the PR patch. Not actively foraging in the PR patch was defined by 15 s without a bar touch or the press of the floor panel, or by entry into the CRF patch, whichever came first. Time in the PR patch prior to satisfying the criterion was not counted in the operant response. This criterion for determining presence in a patch was used in Timberlake *et al.* (1987) and proved to reflect accurately the location of the rat.

The 6-min access time to the CRF was chosen to allow completion of the initial bout of continuous eating and usually provided sufficient food to maintain the animal at 85% with little or no supplemental feeding. The 4 rats in Group MT (matched-time) were provided with their 6-min access to food in the CRF patch at the average time at which the rats in Group ET earned access under a particular delay requirement. For the purpose of this average, if an animal in Group ET failed to complete a particular delay requirement within the allotted session time, it was assigned a time equal to the session length. The rats in Group MTNF (matched-time no-food) were removed from the apparatus at the same average time as the rats in Group MT received CRF access.

For the 2- to 32-min delay requirements, the time available for the rats in Group ET to cumulate the required delay was a maximum of 64 min. For the 64-min requirement the time allotted was a maximum of 96 min. Because no animal completed the 64-min requirement, it was designated the baseline condition for animals in Groups MT and MTNF. For rats in Group ET the baseline was defined as the first requirement the animal consistently failed to complete. Thus, the baseline conditions ranged from the 16- to the 64-min requirements (see Table 1). The baseline condition was assumed to represent responding in the absence of the anticipation of CRF food. Delay requirements were imposed in an ascending order (2 to 64 min) with 18 to 24 sessions at each requirement to establish sta-

Table 1

Mean number of pellets ingested during each delay condition over mean pellets ingested during the same time interval in the baseline condition.

Group	Subject	Scheduled delay to CRF patch (min)					
		2	4	8	16	32	64
		Eat/Base	Eat/Base	Eat/Base	Eat/Base	Eat/Base	Base
ET	F304	9.3/13.0	11.0/17.7	25.8/28.5	40.0/44.8	47.0*	—
	F305	9.8/19.0	13.5/26.2	34.0/38.5	68.7*	—	—
	F306	3.2/11.2	14.0/18.2	20.5/23.3	23.7/28.8	33.2/41.0	51.2
	F307	4.3/11.5	10.8/17.5	16.3/25.2	11.8/32.0	10.0/38.2	48.8
MT	F405	8.5/13.2	16.3/23.7	27.0/31.2	42.7/43.3	47.3/49.5	64.7
	F406	7.3/15.3	12.3/24.5	19.2/33.0	33.5/47.3	47.2/53.0	64.5
	F407	11.3/16.8	17.7/28.3	29.7/39.2	57.2/60.2	72.2/70.2	90.5
	F408	6.0/6.7	12.5/10.3	19.7/13.5	29.5/20.2	24.8/23.0	26.2
MTNF	F401	10.2/13.2	18.2/21.5	26.2/28.3	34.7/39.3	33.0/43.0	46.5
	F402	9.2/15.8	17.8/26.5	24.8/33.7	43.2/47.8	46.2/52.5	59.0
	F403	10.0/10.3	13.7/16.8	20.5/23.0	32.3/36.3	37.8/42.3	53.0
	F404	6.2/11.5	13.3/16.5	12.7/19.3	19.2/22.0	19.2/22.5	24.0

Note: * indicates baseline if different than last column. The ratios of the scores separated by a slash are plotted as a percentage in Figure 2.

bility of responding. Stability was assessed by superimposing six daily plots of cumulative pellets eaten over time and looking for deviant days. For all animals, any supplement necessary to maintain body weight at 85% of ad lib was provided in the home cage 0.5 hr after the session.

RESULTS

Suppression of Intake in the PR Patch

Figure 1 shows total pellets eaten in the PR patch as a percentage of the local baseline amount averaged over the asymptotic 6 days of each delay requirement. Table 1 shows the absolute intake scores from which these percentages were computed. Each of the panels in Figure 1 shows all 4 rats in a particular group: ET (earned-time), MT (matched-time), and MTNF (matched-time no-food). The local baseline amount eaten was the number of pellets eaten by a rat in the PR patch during a period in baseline equal to the average interval to access to CRF food under a particular delay condition. For Groups ET and MT, the percentage measure allowed each animal to serve as its own control in comparing responding in the presence and absence of delayed access to the CRF patch.

For Group ET the baseline was defined as the first condition in which the rat consistently failed to complete the delay requirement for access to the CRF patch. Table 1 shows base-

line responding was measured in the 16-min condition for Rat F305, the 32-min condition for Rat F304, and the 64-min condition for Rats F306 and F307. The differing conditions for baseline produced the different length lines in Figure 1. For Groups MT and MTNF baseline responding was measured in the 96-min session (the 64-min requirement). For Group MT this was the first condition in which no food was obtained in the CRF patch. For Group MTNF, which never received food in the CRF patch, this was the longest session.

All animals in Group ET (Figure 1) showed a similar large suppression of intake relative to their baseline at the 2-min delay requirement, followed by a rapid decrease in suppression to the 8-min requirement. For Rats F304, F305, and F306, intake by the 8-min requirement was asymptotic between 80% and 90% of baseline. Rat F307 clearly differed from the others in showing a marked decline in intake at the 16- and 32-min requirements. As we will see shortly, this effect seemed to be due to the effort and efficiency of the animal in completing the delay requirement for access to CRF food. As the delay requirement grew larger, F307 continued to leave the PR patch very early in the session rather than postponing its exit proportionally to session length as did the other animals. The result was an increasing relative and absolute suppression of intake and more rapid access to the CRF patch than for the other animals.

Fig. 1. Mean percentage of baseline pellets ingested in the PR patch as a function of delay requirement for access to CRF food. Baseline consists of the first condition in which the CRF patch was not consistently available (Group ET) or the 96-min session (Groups MT and MTNF). The percentage compares the number of pellets ingested under the delay requirement with the number of pellets ingested in baseline during the actual time period for access to CRF food.

Three rats in Group MT resembled the three rats in Group ET in showing the greatest suppression of intake at the shortest delay requirements followed by an increase to a high percentage of baseline intake at the longest requirements. In general, these rats (F405, F406, and F407) showed less relative suppression in the 2-min delay condition than did the rats in Group ET but took one delay requirement longer to reach a slightly higher asymptote. Rat F408 was atypical in showing a percentage intake over 100% for the 8- and 16-min conditions, followed by a decrease in relative intake at the 32-min condition. This pattern of results was created by a marked drop in total intake and rate of intake in the depleting patch in the 32-min condition, a drop that persisted in baseline. Essentially, baseline intake decreased suddenly during the last two conditions, producing an inappropriately small baseline divisor for previous conditions. Such marked decrease in intake typifies the behavior of a sick rat, although we have only modest convergent evidence of weight loss in this case.

For Group MTNF, 2 animals showed no consistent trend in percentage intake over the different conditions. However, the data of Rats F404 and especially F402 resembled those of the majority of rats in Group MT. Their lowest performance occurred in the 2-min requirement and increased slowly to the 16-min requirement. Like Group ET, these animals also showed a clear reduction in intake below baseline at asymptotic responding.

To facilitate comparison of the present results with those of Timberlake *et al.* (1987), Table 2 shows the average time at which food was made available in the CRF patch under each operant delay requirement for each subject in Group ET. Table 2 also shows the averaged delay times for the subjects in Group MT (and MTNF). By noting the delay requirement at which asymptotic responding occurred in Figure 1 and looking up the actual time to the CRF in Table 2, we arrive at time horizons very similar to those reported by Timberlake *et al.* (1987) for animals similar to Group MT. F306 is an obvious exception.

However, in specifying time horizons by suppression of current responding, it is important to examine the pattern of suppression across the delay interval. For example, suppression over the entire interval suggests a time horizon corresponding to the entire in-

terval. Suppression over only the last portion of the delay interval suggests a shorter horizon. Further, as will be seen, suppression over the latter portion of the interval may not be clear from the asymptotic percentage of baseline responding as shown in Figure 1. Figure 2 shows plots of cumulative pellets over time in the PR patch by delay requirements for F306 and F307 from Group ET, F405 from Group MT, and F402 from Group MTNF.

Subjects F306 and F307 showed obvious suppression of responding relative to baseline in the first 2 min of the 2-min and 4-min delay requirements, and the degree of suppression was inversely related to the size of the requirement. F306 showed marked flattening of the cumulative intake curves in the latter half of the 16- and 32-min requirements. These results indicate a time horizon approaching 30 min for the 32-min requirement. Over the same delay requirements, F307 showed an even more marked flattening of intake rate combined with successively greater suppression at the beginning of the session. These data indicate a time horizon approaching 40 min for the 32-min requirement.

Compared to F306 and F307, F405 (Group MT) showed less suppression of intake rate at the shortest required delays and a smaller and more gradual suppression over the latter part of the longer delay conditions. The data of F405 resembled those of F406 and F407 (also in Group MT). The data of F304 and F305 (Group ET) fell between those of F306 and F405 with regard to degree of early suppression and later flattening of intake rate. Finally, F402 (Group MTNF) showed inconsistent suppression at the shorter delay requirements but effects similar to Group MT at the longer delay conditions. The suppression at the end of longer delay conditions also characterized the responding of the other animals in Group MTNF.

The prevalent suppression of intake over the last part of each session length coupled with the apparent tendency for Group MTNF to increase slightly their general rate of intake in the baseline seems to be responsible for asymptotic response levels lower than 100%. It is worth noting that the increase in rate of intake in baseline occurred only for this group and probably was not due to a cumulative change with experience or time. The rats remained at stable percentage body weights (with 1 g of

Table 2

Mean number of minutes at asymptote from the start of the session to access to CRF food for individual subjects in Groups ET and MT.

Group	Subject	Scheduled delay to CRF (min)				
		2	4	8	16	32
ET	F304	4.6	8.8	21.9	54.1	64.0
	F305	4.8	8.2	18.7	64.0	64.0
	F306	3.4	10.5	18.7	29.6	61.0
	F307	2.8	7.6	15.9	24.9	38.9
MT	All	4.0	10.0	18.0	40.0	56.0

Note: The time for all animals in Group MT was set to the mean delay time for Group ET. This mean time cannot be computed from the data for Group ET reported above because the average was calculated using the scores of an additional subject not shown that died before reaching the baseline. The mean delay time for Group ET was also used as the session length for Group MTNF.

growth per week) across all conditions. The effect appeared suddenly at the 96-min session length after a minimum of 74 days in the experiment.

Time Outside the PR Patch

Figure 3 shows two location measures over time for each delay requirement: time outside the PR patch and time in the CRF patch. Data are shown for the same rats as in Figure 2. Comparison of the ET rats (F306 and F307) with F405 from Group MT and F402 from Group MTNF makes clear that the operant contingency on time outside the depleting patch had a dramatic effect. For most intervals, the ET animals spent more than twice as much time outside the PR patch as the MT and MTNF animals, and nearly all of that time was spent in the CRF patch. The MT and MTNF animals differed in that the MT animal more clearly increased time outside the PR patch (and in the CRF patch) just prior to food availability in the CRF patch. Except for the first one or two intervals, the MTNF animal showed a fairly regularly increasing rate of time spent outside the PR patch and did not show a correlated increase in time in the CRF patch.

Table 3 provides quantitative confirmation of these trends for each rat by showing the average number of seconds per minute spent outside the PR patch and inside the CRF patch during the last 2 min before food became available (or the session ended for Group MTNF). For all conditions except baseline the animals

Fig. 2. Mean cumulative number of pellets eaten for each delay requirement (2, 4, 8, 16, and 32 min) and for baseline (dotted line) plotted by 2-min bins. The data shown are for Subjects F306 and F307 in Group ET, Subject F405 in Group MT, and Subject F402 in Group MTNF. Note that the number of pellets eaten is equivalent to the PR value paid per pellet.

in Group ET averaged more than 50 s outside the PR patch and inside the CRF patch. The animals in Group MT generally averaged about half of that time outside the PR patch, but like Group ET spent nearly all of the time outside the PR patch in the CRF patch. The animals in Group MTNF spent even less time outside the PR patch (until the 32-min requirement), and a much smaller proportion of that time was spent in the CRF patch.

DISCUSSION

The addition of an operant response providing access to less costly future food seemed

to extend the potential time horizon of feeding rats to at least 39 min for F307 and to approximately 30 min for F306. Rather than maintaining its previous intake of pellets in the depleting patch, F307 actually decreased its absolute intake in the depleting patch at the 16- and 32-min requirements. In other words, the animal left the depleting patch at successively lower values of the PR as the requirement for access to less costly food was raised above 8 min. This behavior was in the direction of increasing the net benefit per unit time computed over a period approaching 45 min, and clearly indicated a time horizon of approximately that length.

Fig. 3. Mean time outside the PR patch (top panel of each plot) and inside the CRF patch (bottom panel of each plot) for each delay requirement (2, 4, 8, 16, and 32 min) and for baseline (if different than one of the above) plotted by 2-min bins. The data shown are for Subjects F306 and F307 in Group ET, Subject F405 in Group MT, and Subject F402 in Group MTNF.

Table 3

Mean number of seconds per minute at asymptote spent outside the progressive-ratio patch (left score in each column) and inside the CRF patch (right score in each column) during the last 2 min before access to CRF food (the end of the session for Group MTNF).

Group	Subject	Scheduled delay to CRF patch (min)					
		2	4	8	16	32	64
		Out/CRF	Out/CRF	Out/CRF	Out/CRF	Out/CRF	Out/CRF
ET	F304	60.0/59.7	60.0/60.0	60.0/56.4	50.5/50.5	13.3/10.3*	—
	F305	46.8/45.8	53.5/53.5	49.3/49.2	8.8/4.0*	—	—
	F306	46.5/45.2	49.2/48.7	50.8/48.9	60.0/53.4	52.6/48.7	21.8/16.8
	F307	52.5/52.5	60.0/58.9	60.0/59.4	60.0/57.7	60.0/51.3	50.3/20.0
MT	F405	32.3/32.3	27.5/27.5	25.0/25.0	24.6/24.6	24.1/21.0	28.6/25.2
	F406	36.1/34.3	38.1/36.6	32.0/30.9	47.0/46.5	57.5/53.9	42.7/42.0
	F407	15.7/15.7	16.4/16.3	3.9/3.9	17.3/17.3	3.7/3.3	21.0/12.3
	F408	29.7/27.4	21.9/21.2	14.0/12.1	12.4/8.6	49.0/2.8	41.0/12.6
MTNF	F401	15.0/15.0	2.0/2.0	19.4/18.0	17.0/5.1	27.5/13.4	34.0/8.9
	F402	11.4/10.5	7.8/7.7	25.5/13.4	9.1/4.3	32.8/22.0	43.5/3.9
	F403	2.7/0.0	14.6/11.3	28.4/13.9	19.5/5.0	25.6/7.4	33.0/11.1
	F404	24.5/9.1	24.9/13.2	52.8/14.0	37.0/10.1	49.0/9.9	53.0/11.2

Note: * indicates baseline if different than last column. The entries consist of the mean time out of the PR patch over the mean time inside the CRF patch.

The 2 other animals in Group ET showed a marked suppression of intake only through the 4-min requirement, suggesting a time horizon no greater than 20 min and possibly as brief as 8 min (see Table 2). However, even at asymptote the cumulative-pellets-eaten measure (not shown for these animals) revealed continued suppression over the last portion of the interval. In other words, these animals and F306 showed suppressive time horizon effects not obviously indicated in the asymptotic summary data in Figure 1. These results, coupled with those for Group MTNF, argue strongly that an assessment of time horizons in this paradigm must examine the rate of intake across the session, not just summary statistics for each condition.

Three animals in Group MT (the matched-time Pavlovian procedure) also showed suppression of food intake at the short delays followed by a steady decrease in suppression with longer intervals. These animals averaged less suppression and took longer to reach a stable percentage of baseline intake with increasing delay intervals than did the 3 comparable animals in Group ET. Again even at asymptote there was little suppression of intake during the latter portion of the delay interval.

The results for animals in Group MTNF provided a surprise. Although 2 animals showed no differential suppression of intake

in the shortest delay intervals, 2 others did show an initial suppression (F404 and especially F402). Further, inspection of the cumulative food intake plots showed that at asymptote all the animals in Group MTNF showed some suppression of intake in an amount similar to that for animals in Group MT prior to the end of the session.

For these animals the paradigm resembled a time-limited foraging test in which the effects of changing the session length are explored. However, the direction of any present effect is the reverse of the typical time-limited foraging effect in which shortening the session seems to produce an increase in the intensity of foraging (Dow & Lea, 1987; Lucas, 1987). Another explanation for the effect is that the animals are anticipating the aversive consequences of handling. One might think that the aversiveness would be eliminated over the course of several months of associating handling with feeding, or continue to be so strong as to produce a greater decrease in feeding, but the alternative cannot be ruled out.

However, on the basis of other data we suggest that the animals suppressed rate of ingesting pellets at the end of the session because of the receipt of their daily ration 30 min after removal from the experimental chamber. Certainly F307 showed that rats were capable of bridging a gap to food of more than 39 min. Further, research by Flaherty and Checke

(1982) and by Lucas, Gawley, and Timberlake (in press) also argues for a time horizon that long, especially when a large amount of food is involved. Whatever the explanation, the results of Group MTNF strongly argue for caution in interpretation, multiple measures, and convergent techniques in testing time horizons.

The failure of the operant requirement to extend the time horizon more consistently might be attributed to the unorthodox nature of the operant (time outside the depleting patch) and a resultant difficulty in learning or performing it. However, our experimental procedure shaped the animals to perform the response by beginning with a low schedule requirement and increasing it, spending at least 18 days at each requirement. Further, the data in both Figure 3 and Table 3 show that the schedule requirement had a marked effect on the response as we defined it. Time outside the depleting patch was much greater for animals in Group ET than in Groups MT or MTNF. In the last 2 min before CRF food became available, the animals in Group ET spent nearly all their time outside the PR patch and almost all of that in the CRF patch.

The animals in Group MT showed that response-independent access to less costly food in the CRF patch had a similar qualitative effect on behavior. These animals also increased time spent outside the depleting patch as the access time came closer, and nearly all of that time was spent in the CRF patch. However, the time spent was only about half that spent by the animals in Group ET. In contrast, the animals in Group MTNF showed no anticipation of food in the CRF, and most just slowly increased their time outside the depleting patch as the session continued.

Another explanation for why the operant requirement failed to increase the time horizon more consistently is that the cost to the animals of responding on the PR schedule was not great enough to have an effect. Although the cost on a large fixed-ratio schedule might be consistently greater, the cost for a pellet on the present PR schedule reached over 40 pellets for 7 of the 12 animals (see Figure 2 in which the cumulative-pellets measure can be read as the PR value). Further, the present PR schedule had already been shown to be costly enough to produce suppression (Timberlake et al., 1987). The question here was whether the

range of suppression would increase, and, because this would occur at the high-cost part of the schedule, the cost manipulation seemed adequate so long as no fixed conclusions are drawn about absolute time horizons.

A critical aspect of research on time horizons is the growing evidence that the characteristics of the test paradigm produce effects that complicate and perhaps confound the investigation (e.g., Lucas et al., in press; Shettleworth & Plowright, in press; Timberlake & Peden, 1987; Timberlake et al., 1987). In the introduction we noted the possibility that an indicated time horizon is strictly a function of peripheral response competition for a final common pathway of expression (McFarland & Sibly, 1975). Simply put, the animal cannot be in the PR patch and the CRF patch at the same time. The present data support the existence of competition in that, prior to access to CRF food, feeding in the PR patch decreased dramatically as the animals spent essentially their entire available time in the CRF patch. However, except for F307 and to a lesser extent F306, this competition did not produce longer time horizons for the animals, only greater suppression at a particular interval.

We conclude that competition is an inevitable outcome of a paradigm with exclusive alternatives, but it is not the sole or primary determinant of the indicated time horizons. Support for this view is provided also by results from testing paradigms that do not provide alternative responses or locations. For example, the anticipatory contrast paradigm of Flaherty (e.g., Flaherty & Checke, 1982) places a temporal gap between a short period of ingestion of one substance and a period of access to a second in the same location. Thus, neither anticipation of food at an alternative location nor as the result of a different response can serve as mediators of competition. Under these circumstances animals still show suppression of saccharin-drinking in anticipation of a future sucrose solution at between a 32- to 37-min delay (Flaherty & Checke, 1982; Lucas et al., in press; see also Bacotti, 1976).

In summary, the present data extend to about 40 min the time horizon in rats over which a less costly future food can have a suppressive effect on current feeding. The effect was clearest for F307 and present in F306, both animals in the earned-time group. Feeding-related suppression may also have occurred for the

animals in Group MTNF separated from their daily home-cage feeding by a comparable time period. However, for the remaining animals in Group ET and those in Group MT, a time horizon of 15 to 20 min seemed appropriate in the present circumstances. Thus, despite markedly increasing operant responding and the opportunity for competition, specification of an alternative operant response leading to less costly future food does not necessarily increase its suppressive effects. Further, increased and response-independent food deprivation did not increase the time horizons of the MT group over that shown by Timberlake *et al.* (1987).

What other variables might increase the temporal extent of the suppressive effects of future food? The most reasonable candidate is an increase in the relative importance of future food, either by increasing the cost of current food or by increasing the attractiveness or amount of future food. Also, use of a nondepleting schedule would have the advantage of removing the correlation between the cost of the pellet, the amount of previous intake, and the time remaining in the session. It seems likely, though, that any notion of a single basic time horizon, like the concept of optimal foraging, may oversimplify the complex determinants of behavior. There are many reasons to expect that time horizons have been selected to vary with circumstances and function.

Combined with the research indicating the importance of rules of thumb in foraging (e.g., Stephens & Krebs, 1986), the research on time horizons further reveals the degree of complexity of foraging behavior. The evidence for specific diet requirements, multiple regulatory and anticipatory processes, and time-limited memory for differentiating food locations within a patch (Beatty & Shavalia, 1980; Olton, Handelman, & Walker, 1981) suggests that foraging is the product of the fit of many processes and mechanisms with the environment. The role of time horizons in this fit seems to be quite important.

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