

## TO WAIT OR TO RESPOND?

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Emitting a certain response and waiting for a specified time without making that response had the same consequence. In Experiment 1, food-deprived pigeons were as likely to wait as to respond only if waiting provided food at a much higher frequency than did pecking. In Experiment 2, the consequence for humans was a brief light flash and tone. People were not biased for responding over waiting. Instead, their choices suggested crude payoff maximization. In Experiment 3, pigeons again obtained food, but they were not food deprived and could eat freely at each opportunity. Their behavior was more like that of the humans of Experiment 2 than that of food-deprived pigeons given small quantities of food at each feeding opportunity. The three experiments together showed that biases for responding over waiting were neither inherent characteristics of species nor inevitable outcomes of particular schedules. Choice between active search and waiting depended on ecological-motivational factors even when species and schedules were held constant.

*Key words:* choice, foraging, open and closed feeding economy, waiting versus responding, differential reinforcement of not responding, motivation, key peck, key press, pigeons, humans

Foragers can get food either by active hunting or by waiting for prey to appear. For example, adult pigeons are hunters that search for grain or insects and worms or beg food from humans, but they waited for food as nestlings (Levi, 1963). Laboratory experiments (Zeiler, 1976, 1977, 1979; Zeiler & Solano N., 1982) showed that adult pigeons could get food either by waiting for a specified interval without pecking (a DRO or differential-reinforcement-of-not-responding schedule) or by pecking. Either waiting or responding could be the dominant foraging pattern. Which they did depended on how long they had to wait to get food. The shorter the required wait, the more they paused.

However, the pigeons clearly were biased in favor of pecking. For them to withhold pecks, waiting had to provide food much more often than did pecking. They would not wait for 30 s if pecking yielded food every 100 s on average (Zeiler, 1977), nor would they wait 60 s when pecking produced food every 180 s (Zeiler, 1976). They emitted 100 pecks rather than wait 30 s (Zeiler, 1977).

A bias for active search over waiting may be characteristic of adult pigeons and other animals, but this bias also might depend on the context provided by particular foraging sit-

uations. The present research further explored the nature of choice between emitting and withholding the same response. Experiment 1 found the waiting requirement that would result in pigeons obtaining food equally often by pecking and by waiting. The possibility that the points of equivalence were peculiar to pigeons under particular deprivation and feeding conditions led to Experiment 2, which studied humans under the same schedules, and then to Experiment 3, which investigated whether pigeons would show the same patterns when they were not food deprived and were allowed to eat freely at each feeding opportunity.

## EXPERIMENT 1

Zeiler and Solano N. (1982) generated equal numbers of food deliveries from pecking and waiting by increasing the DRO value following food acquisition via a wait and decreasing it after a feeding obtained via pecking. The one condition of that study did not examine how or if the DRO value that led to equal feeding from the two foraging strategies depended on parameters of the schedule providing food for responding, so it could not allow general conclusions about the choice process.

The present experiment used five different random-interval (RI) schedules for pecking, and then added an adjusting DRO schedule. The intent was to find the DRO value that

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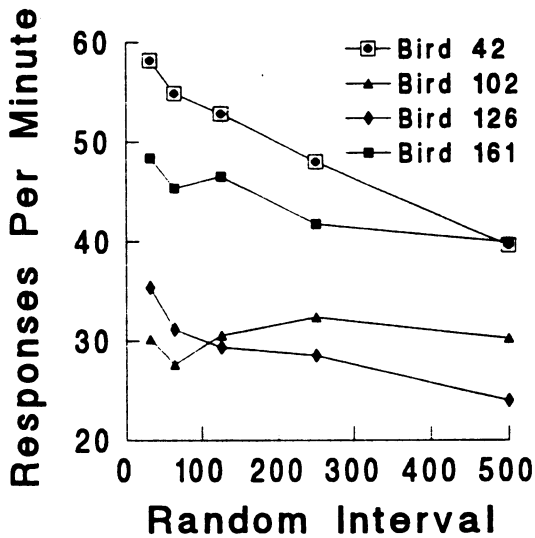


Fig. 1. Response rate for each RI schedule (Experiment 1).

resulted in equal food presentations from waiting and responding under a range of RI schedules.

#### METHOD

##### Subjects

Four adult White Carneau pigeons were maintained at 80% of their free-feeding weights. Birds 102 and 126 were female; Birds 42 and 161 were male. Birds 42 and 102 had been in prior experiments; Birds 126 and 161 were experimentally naive.

##### Apparatus

The experimental chamber was 36 cm long, 32 cm wide, and 35 cm high. The pigeon stood on a platform made of wood dowels, each 2.6 cm apart. A 1-W white light in each upper corner of the response panel provided general illumination. The single Gerbrands response key (1.9 cm diameter) was centered 21 cm above the platform and could be lit from behind by two 1-W green lights. The key was activated by a force of at least 0.18 N. An aperture (5 cm square) under the key and 9 cm above the platform gave access to Purina Pigeon Checkers® (the birds' standard diet). During the 3-s feeder cycles, the aperture was illuminated by a 1-W white light, and all other lights were turned off. Continuous white noise helped mask extraneous sounds. Experimental events were programmed and recorded by a

Digital Equipment Corporation PDP-8A® computer operating under SUPERSKED® software (Snapper & Inglis, 1979).

##### Procedure

Each pigeon had five random-interval (RI) schedules both with and without an accompanying DRO schedule. The RI schedules were controlled by a probability gate tested by pulses at 1-s intervals. The first key peck emitted after a test was passed resulted in food delivery. Probability settings of .032, .016, .008, .004, and .002 produced RI schedules with nominal mean interfood intervals of 31.25, 62.5, 125, 250, and 500 s. If DRO prevailed as well, food delivery also occurred if the bird did not peck for the time specified by the current DRO value.

The schedules were nonindependent. Pecks that produced food from the RI schedule restarted the DRO interval, and food delivery from DRO canceled any feeding opportunity that may have become available for pecking.

The DRO value incremented or decremented depending on how the last feeding occurred. If it was from the RI schedule, it decreased by 1 s; if it was from DRO, it increased by 1 s. In the first session of a condition, the DRO value began either at 10 s or at 60 s; in all others, it began where it ended in the preceding session.

The first of each pair of conditions involved an RI schedule in effect alone; the second had that RI schedule imposed conjointly with DRO. The order of RI schedules was randomized, with the restriction that no 2 birds had the same schedule at any one time. After every bird had all five RI and conjoint RI DRO pairs, the pairs were reimposed in a different order for each one. A condition lasted for 30 sessions. Sessions were conducted 5 days per week and ended after 30 feeder cycles.

#### RESULTS

All data analyses were based on the last seven sessions of a condition. Figure 1 shows response rates averaged over the two replications of the baseline RI schedules. For Birds 42, 102, and 126, rate in each session was within 10% of the overall average. Rate declined as mean interval size increased for Birds 42 and 126. The reversal for Bird 161 was due to the second exposure to RI 125 s. Taking only the first replication, the rate of 42.6 re-

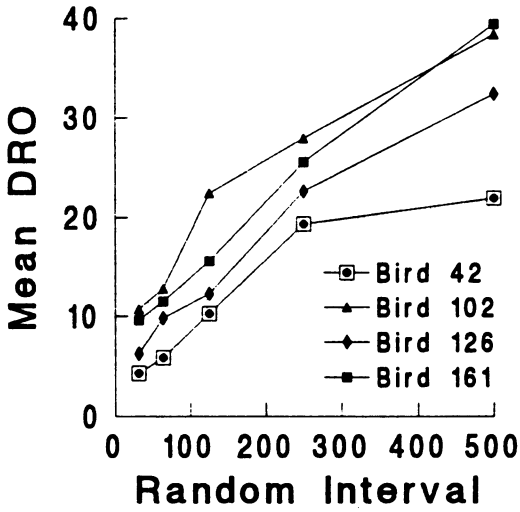


Fig. 2. Mean DRO value with DRO and RI schedules imposed together (Experiment 1).

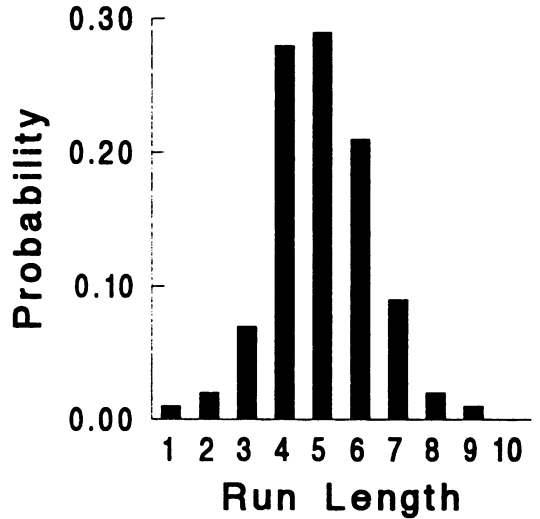


Fig. 3. Probability of runs of food deliveries of various lengths from the same schedule (Experiment 1). Runs terminated by the end of the session were not included.

sponses per minute also fit a monotonically declining function. For Bird 102, rate did not change systematically with RI value.

When the DRO schedule was added, food deliveries per session from RI and DRO ranged from equality to a majority of three for one option. Calculation of the DRO value prevailing when food deliveries shifted from one source to the other was based on Dixon and Mood's (1948) method for staircase procedures, as described by Rosenberger (1970). The Dixon-Mood mean focuses on the value that generated transitions between options. A simple average of all DRO values that occurred is at best an indirect way of assessing the transition point and is more affected by aberrant sequences than is the Dixon-Mood mean. The Dixon-Mood mean is:

$$M = A + d(\Sigma fx' / N) \pm 0.5d,$$

where *A* is the DRO value at which the switch from DRO to RI as the food source occurred most often, *x'* is signed deviations of each such switch from *A* in step units, *fx'* is the frequency weighting of the deviations, *d* is step size in DRO value, and *N* is the number of switches from the DRO to the RI food source. If two or more values qualify as *A*, any can serve as *A*. The Dixon-Mood mean is not distorted, because compensation is inherent when all values are transformed into signed deviation units.

Figure 2 shows the Dixon-Mood mean DRO value over the last seven sessions of a

condition averaged over replications (replications produced means that never differed by more than 10%). Inferential statistics (Rosenberger, 1970) showed that all means increased significantly (*p* < .05) with longer RI schedules. Power functions relating mean DRO to the RI average interfood interval had exponents of 0.64, 0.48, 0.60, and 0.52 for Birds 42, 102, 126, and 161, respectively.

Food presentations from DRO and RI did not occur at random. Food received via one of the schedules was followed by more food obtained in the same way, until finally the bird switched to the other schedule. Figure 3 shows the probability of run lengths of successive food deliveries from one source. Data were combined over birds, RI schedules, and runs involving DRO or RI food deliveries, because analysis of variance of run lengths showed no statistically significant main effects or interactions for birds, schedules (RI or DRO), or RI values (*p* > .4 in every test). A runs test (Siegel, 1956) revealed that choices occurred more frequently in clusters than would be expected by chance (*p* < .01). Alternation of runs between RI and DRO accumulated to yield the overall approximately equal food deliveries from RI and DRO choices in each session.

The first feeding of the day was from the RI schedule. The schedule involved in subsequent runs depended on the prevailing DRO value but not on the immediately preceding

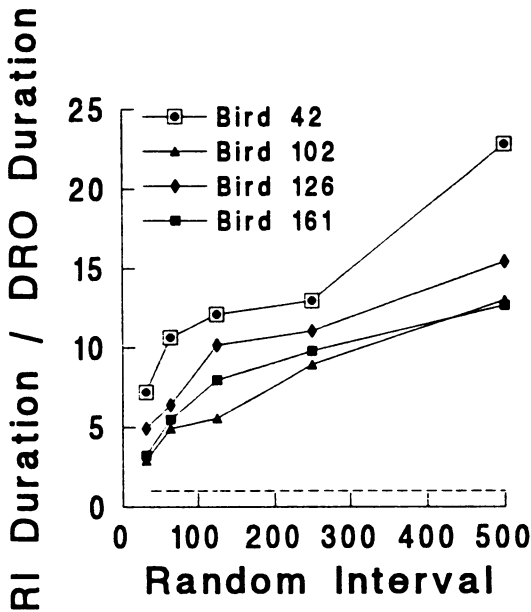


Fig. 4. Ratio of mean RI run-length durations to mean DRO run-length durations in Experiment 1. The horizontal dashed line corresponds to equal run-length durations.

RI interfood interval. The shortest DRO values generated food delivery from DRO, and the longest resulted in food delivery from RI. The momentary DRO value always was within 6 s of the Dixon-Mood mean. Sessions rarely produced identical sequences of DRO values, but the following was typical. Denoting RI food delivery as R and DRO food delivery as D, the sequence in one session was R-R-D-D-D-D-R-R-R-R-R-R-D-D-D-D-D-R-R-R-R-R-D-D-D-D-D-R-R-R-D; in another it was R-R-R-R-D-D-D-D-D-D-D-R-R-R-R-R-D-D-D-R-R-R-R-R-D-D-D-D-D-D-D-R.

Behavior during runs depended on whether food was coming from the RI or from the DRO schedule. In an RI run, responding at the same rate as in the baseline conditions began right after the food delivery that started the run and continued up to the food delivery that ended it. In a DRO run, the bird paused immediately after the food delivery that triggered the run and continued pausing through the food delivery that ended the run. No DRO run contained more than two key pecks, and over 92% contained none. A peck sometimes did result in food from the RI schedule. Whether or not it did, the DRO pause resumed immediately.

The sharp transitions between forms of be-

havior leading to RI and DRO food deliveries made it possible to infer how much time the pigeons allocated to each schedule. The time allocated to a schedule had to be the same as the interfood intervals established by the schedule, because runs always began after a food delivery from one schedule and ended after a food delivery from the other. Time spent in a run involving a given schedule was the sum of the times taken by the successive food deliveries from that schedule. The duration of an RI run was the sum of the series of programmed RI interfood intervals in that run plus the times between the end of the programmed interval and the next response. The average interfood interval over the last seven sessions of a condition exceeded the nominal RI value by 5% to 10%. The average duration of DRO runs had to be the same as the mean DRO value plus the time lost by the occasional responses that reinitialized the DRO timer. The average time spent in obtaining a food presentation from the DRO schedule never exceeded the mean DRO value by more than 4%.

Figure 4 shows the ratios of average RI run durations to average DRO run durations. The ratio increased with each successively longer RI schedule. This shows that the pigeons always spent more time in the RI than in the DRO option, with relative time increasing with the longer RI schedules. It also means that the DRO schedule always provided food at a much average higher rate than did RI, with the advantage increasing with each longer RI. The DRO food rate (per second) was approximately the square of RI food rate (per second).

DISCUSSION

Alternation between sustained periods of pecking at baseline rates and waiting without pecking meant that pigeons responded as if either the RI schedule or the DRO schedule prevailed. The data implied choice between the DRO and RI alternatives, with choice defined either in terms of a distinctive form of behavior or in terms of the source of food.

Theories of preference have emphasized how choice relates to the returns gained from the various options (see Williams, 1992, for a review of molar maximizing, momentary maximizing, and matching theories). Experiments of primary interest have involved choices between spatial locations (concurrent schedules

in which alternatives occur on a different key or lever) or between other stimuli (concurrent schedules in which responding to a key or lever changes the prevailing stimulus and contingencies). Concepts that explain how animals choose where to direct a response are not easily applied to the present data. Choice between emitting and withholding the same response raises conceptual problems about the nature of responses that have received little attention.

Consider the basic matching relation. The proportion of behavioral resources allocated to an alternative should match the proportion of food obtained from that source. In the present experiment, equal food deliveries from each source did not seem to correspond to equally frequent kinds of behavior. The RI schedules generated many pecks per food delivery, whereas the DRO schedules generated one pause. Equal responses per food delivery would require the same number of relevant behavioral types. For that to have been the case, either the entire sequence of pecks per RI food delivery must constitute one unitary response, or the single pause per DRO food delivery must be a sequence of short pauses that occur at the same rate as did key pecking on the RI schedule. The point is that matching cannot explain these results without considering the nature of response units. At best, matching theory can only acknowledge that biases occurred.

The time allocated to each type of behavior can replace response frequency as the behavioral resource and thereby might bypass the response-unit problem. However, equal time was not spent in the two alternative forms of behavior. At least twice as much time, and as much as 20 times more, was spent in the RI component as in the DRO to obtain the equal food presentations. In direct opposition to matching, the relative rate of food presentations and relative time allocation were inversely related.

Nor did the behavior maximize rate of food acquisition. The birds did get food faster by both pecking and waiting than they would have gotten from exclusive dedication to either form of behavior. As long as the DRO value was kept shorter than the mean interfood time arranged by the RI schedule, the rate of food delivery from both pecking and waiting had to be higher than that available from pecking alone. The highest possible food rate would

have occurred had the birds driven the DRO value to its minimum level by choosing the RI exclusively and then switched alternatives after each food delivery. But they neither drove the DRO schedule down to its lowest possible level nor switched after each feeding. Nor did they reflect momentary sensitivity to likelihood of food delivery from the other alternative. The more time spent pausing, the more likely food would be available from the RI schedule. Yet the birds switched to the RI only after they received food for waiting, and at that point any potential food available for pecking was canceled. In short, the behavior did not show matching, nor did it maximize the overall rate of food delivery, nor did it reflect sensitivity to the local rates of food delivery from each alternative.

Optimal foraging theory (cf. Stephens & Krebs, 1986) is a maximizing theory that treats type of behavior and schedule requirements for obtaining food as equally important. Choices maximize net caloric intake, which means obtaining the most food with the least energy expenditure. Energy expenditure provides a way of comparing different forms of behavior. However, for that to explain the present results, the energy consumed by pausing for the mean DRO value would have to be equivalent to that used in pecking continuously for more than twice as long in some conditions and over 20 times longer in others. The reality of that possibility could not be determined in this laboratory.

Accounting for these data requires explaining why pigeons were so biased in favor of pecking over not pecking as their search strategy. In order for the birds to obtain food equally often from responding and from pausing, waiting had to provide food at a much shorter average interval than did pecking. The degree of bias was reflected by equal outcomes that occurred only when the rate of food delivery for pausing was approximately the square of the rate of food delivery for pecking. Whether this mathematically simple relation is a general rule for pause-response equivalence or was an accident of the effects of this particular experimental arrangement remains unclear.

## EXPERIMENT 2

The data of Experiment 1 fit others showing that pigeons do not readily withhold key pecks.

Many autoshaping experiments (cf. Schwartz & Gamzu, 1977) have found that pigeons peck even at a cost in food acquisition, and pigeons required to space responses may rarely wait long enough to be successful (e.g., Skinner & Morse, 1958). Humans have been more prone to withhold responses, at least in timing situations (Zeiler, Scott, & Hoyert, 1987). Perhaps the bias for pecking over waiting in Experiment 1 reflected proclivities of pigeons foraging for food rather than a principle having more universal application.

As a first step in assessing the generality of the results of Experiment 1, Experiment 2 studied adult humans. Here, the situation involved neither food deprivation nor food as the consequence of completing a schedule requirement. Given that the species also differed, the same results here as in Experiment 1 would encourage the pursuit of a quantitative law of when emitting a response and waiting without responding become functionally equivalent forms of foraging behavior.

## METHOD

### *Subjects*

Four adult humans served as subjects. They volunteered to participate without compensation as a favor to the experimenter. Three of the subjects were not told the nature or purpose of the research until participation was completed; the fourth knew all of the details of the procedure.

### *Apparatus*

The single Gerbrands response key (1.9 cm diameter) could be lit from behind by two 1-W green lights. It was activated by a force of at least 0.18 N. During the 1-s feedback cycles provided for appropriate performance, two red pilot lights located in the two upper corners of the panel were illuminated, the key was darkened, and a tone sounded. Experimental events were programmed and recorded as in Experiment 1.

### *Procedure*

Subjects were shown the response panel and were read the following instructions before the first session:

Thank you for agreeing to take part in this project. As I told you before, participation in-

volves twelve sessions. Each session will end after 30 feedback cycles or after 1 hour, whichever comes first. A feedback cycle consists of a brief flash of the red lights in each corner of the panel. A tone will sound at the same time. Feedback cycles can occur whenever this round disk [experimenter points to the response key] is green. You can press the disk if you want. It is up to you to decide how to get feedback cycles.

Each subject had four RI schedules for key pressing both with and without an accompanying DRO schedule. After one session with RI in effect alone, two sessions had the DRO schedule added. The order of RI schedules was randomized. Sessions ended after 30 feedback cycles or 1 hr, whichever came first.

The procedure duplicated that of Experiment 1 as closely as possible. The RI schedules had nominal average intervals of 31.25, 62.5, 125, and 250 s. If DRO also prevailed, a feedback cycle also occurred whenever a press did not occur for the time specified by the DRO schedule. Both schedules began timing anew after each feedback cycle. If the last cycle was from RI, the DRO value decreased by 1 s; if it was from DRO, the value increased by 1 s. In the first session, DRO began at 60 s; in the second, it began at the value in effect when the previous session ended.

## RESULTS

Figure 5 shows response rate for the single sessions when RI was in effect alone. Rate decreased as interval size increased (with one reversal for S3).

As in Experiment 1, the conjoint RI DRO schedules generated nearly equal payoffs from each source. However, now subjects were as likely to switch schedules after a payoff as to persist in the same one. Figure 6 shows the distribution of run lengths in the last session of the conjoint schedule. Runs tests were never statistically significant ( $p > .30$  for every condition). Denoting a payoff from RI by R and one from DRO by D, the following are samples of sequences in the last sessions: R-R-D-R-R-D-R-D-D-R-D-R-R-D-R-D-R-R-D-D-R-D-R-D-R-D-R-D-R-D and D-D-R-R-R-D-R-D-D-R-D-R-D-R-D-D-R-R-D-R-D-R-D-R-D-D-R-R-D-R.

Each feedback cycle was followed either by a pause that satisfied the DRO requirement or by one to eight key presses separated by

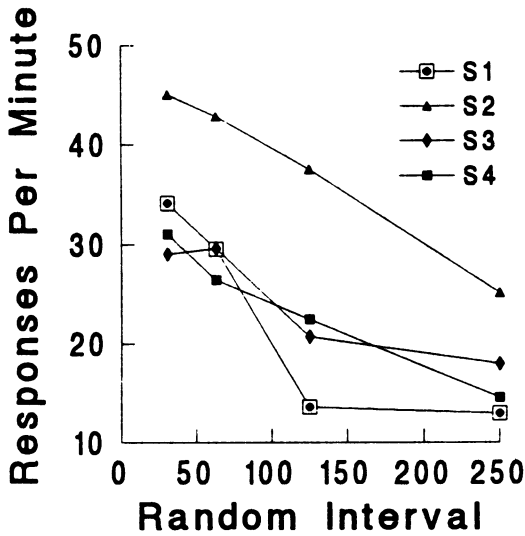


Fig. 5. Response rate for each RI schedule (Experiment 2).

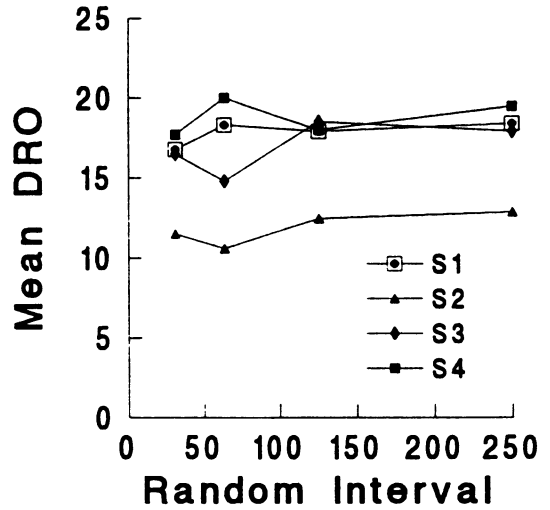


Fig. 7. Mean DRO value with DRO and RI schedules imposed together (Experiment 2).

interresponse times of 10 to 15 s. If a press failed to produce a feedback cycle, the subject then paused long enough to meet the DRO requirement. Because entire periods often involved two kinds of behavior, neither time allocation nor local rate of return could be calculated with certainty for each schedule.

Figure 7 shows the Dixon-Mood mean DRO value in the last session. Mean DRO

seemed independent of the RI schedules. Momentary DRO values never varied from the mean by more than 4 s.

DISCUSSION

The pigeons of Experiment 1 alternated their baseline response rates with long pauses, but people alternated long interresponse times with pauses long enough to meet the DRO requirement. The effect of RI value appeared to be only to increase the number of probes for availability of a feedback cycle from RI. The result was that people kept the DRO value somewhat longer than the average interresponse time for key pressing. They avoided the longest intervals arranged by the RI schedule, because shifting to DRO after emitting a few responses restarted the RI timer. Of course, this also meant that they lost out on any payoff that might have become available between the time of the last response and the end of the DRO period.

The data revealed neither the quantitative relations between mean DRO and RI value found in Experiment 1 nor any preference for responding over pausing. The behavior (and verbal reports from the subjects following the final condition) fit the following hypothesis. The subjects were choosing between the RI and the DRO schedules. They either waited for the DRO to elapse or they began each period by pressing the key as a probe for availability of faster payoff from the RI. When the

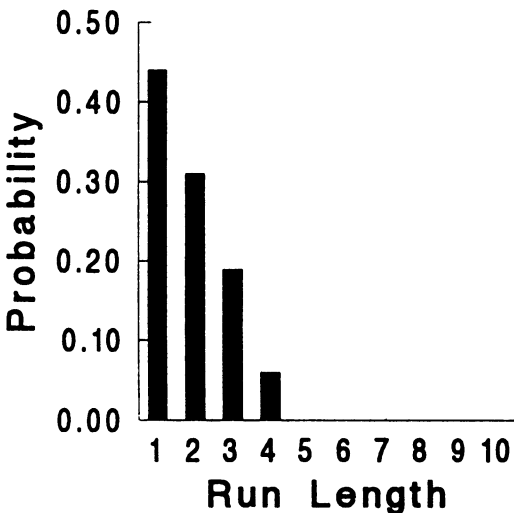


Fig. 6. Probability of runs of food deliveries of various lengths from the same schedule (Experiment 2). Runs terminated by the end of a session were not included.

probe worked, they repeated the same behavior. When it failed, they waited for payoff via the DRO.

This strategy qualifies as a crude form of local maximizing in that the subjects avoided the longer interreinforcer times established by the RI schedule. If they had been as biased in favor of responding as were the pigeons of Experiment 1 or had adjusted their pauses relative to the value of the RI schedule, they would have reduced the rates of return.

### EXPERIMENT 3

Experiments 1 and 2 showed that pigeons and humans differed in how they chose between emitting a response and waiting without responding as alternative ways of obtaining the same outcome. However, the procedures differed in more ways than species of subject. The pigeons were food deprived to maintain them at 80% of their free-feeding weights and obtained food as the consequence of their behavior. The humans obtained only lights and tones and escape from the experimental situation. The procedures surely differed in significance of consequences.

Feeding conditions affect how pigeons and other nonhumans behave. Response rate, choice, and timing processes depend on whether animals forage in an open or a closed feeding economy (Collier, 1983; Hursh, 1980; Timberlake & Peden, 1987; Zeiler, 1991). In an open economy, the animal is food deprived, the experimenter sets the size of each feeding, and the animal gets additional food as needed. In a closed economy, the animal is not food deprived, and food amount depends solely on the animal's interactions with its environment.

Perhaps the strong bias in favor of pecking in Experiment 1 was a product of the open economy used in that study. Experiment 3 investigated this possibility.

### METHOD

#### *Subjects*

The two adult White Carneau pigeons were experimentally naive. Bird 118 was male, and Bird 187 was female.

#### *Apparatus*

Two experimental chambers were as in Experiment 1, but with a second key added. The schedule key could be lit from behind by two

1-W green lights, and the feeder key could be lit by two 1-W red lights. Experimental events were programmed and recorded as in Experiment 1.

#### *Procedure*

The birds first had a closed economy, then an open economy, and then a closed economy once again. The schedules were RI in effect alone or in effect conjointly with DRO. The conjoint schedules were nonindependent, in that food received from DRO canceled any food then available from RI, and every response that potentially could yield food from RI reset the DRO timer. Both closed-economy sequences involved five RI schedules (31.25, 62.5, 125, 250, 500 s) imposed in random order for each bird, first without and then with an accompanying DRO schedule. The open-economy sequence involved RI 31.25, RI 125, and RI 500 s in different order for each bird, first without and then with the DRO schedule. Conditions of the first two sequences lasted 30 sessions. Conditions of the last sequence entailed 10 sessions. Sessions occurred 5 days per week.

*Closed economy.* In closed-economy conditions, the birds were not food deprived. Completion of an RI or DRO requirement turned the schedule keylight off and the feeder keylight on. A feeder-key response resulted in a 3-s feeder cycle. This continued until the bird allowed 30 s to pass without responding. The feeder key then became dark, and the schedule key became green. Sessions ended after 8 hr. The birds had free access to food on weekends. The starting DRO in the first sequence was 10 s for Bird 118 and 80 s for Bird 187. It was 60 s in the second sequence.

*Open economy.* The birds were maintained at 80% of their free-feeding weights. Food delivery was initiated by a response to the feeder key as in the closed economy, but the feeder key was darkened and the schedule key became green after one 3-s cycle. The starting DRO value was 80 s for Bird 118 and 10 s for Bird 187. Sessions ended after 30 feeder cycles. Supplementary feeding was provided as needed to maintain body weights at the 80% deprivation level.

### RESULTS

Figure 8 shows response rates over the last seven sessions of each replication combined.



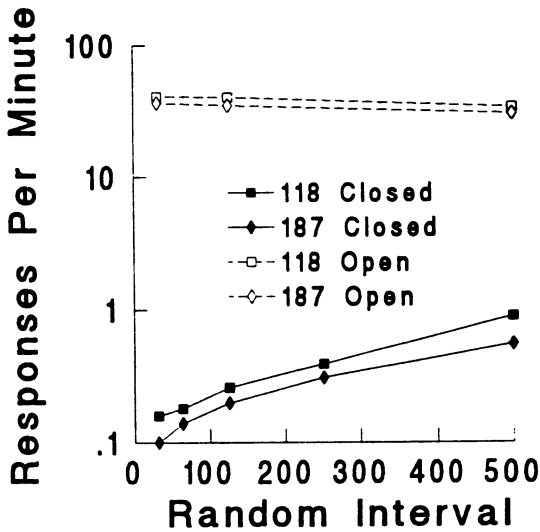


Fig. 8. Response rate for each RI schedule in the closed and open economies (Experiment 3). The y axis is on a log scale.

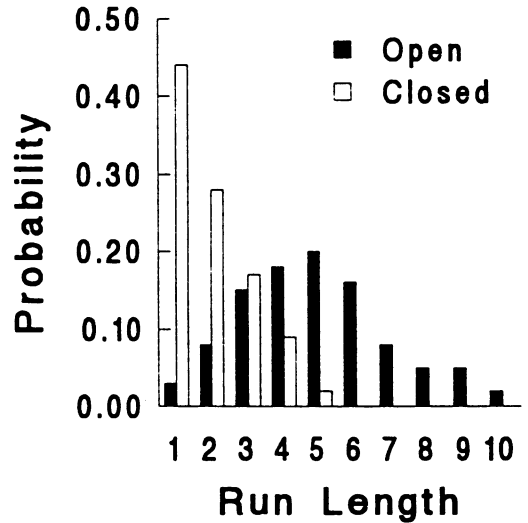


Fig. 9. Probability of runs of food deliveries of various lengths from the same schedule (Experiment 3). Runs terminated by the end of a session were not included.

Rate in each individual session was within 10% of the seven-session means, and the two means never differed by more than 10%. Response rates differed under each economy. (a) The curves changed in opposite directions. In the open economy (as in Experiment 1, which also used an open economy), rate decreased with longer RI schedules. In the closed economy, rate increased. (b) Rates were considerably higher in the open economy (note that the y axis in Figure 8 is on a log scale). (c) Times to the first peck following each food delivery always exceeded 25 s and were as long as 26 min in the closed economy. Time to the first peck in the open economy never exceeded 10 s and usually was 3 s or less.

When DRO was added in either economy, food occurred equally often ( $\pm 2$ ) from DRO and RI in the last seven sessions of each condition. Figure 9 shows how run lengths of food deliveries varied with the economy. In the closed economy, a runs test was not statistically significant ( $p > .20$ ), which meant that neither fewer nor more feedings occurred in succession from the same source than would be expected by chance. In the open economy, food presentations from one source occurred in groups, and a runs test showed that clusters of food deliveries from one schedule were more frequent than would be expected by chance ( $p < .01$ ).

In the closed economy, each food delivery

was equally likely to be followed by a pause long enough to meet the prevailing DRO requirement or by one or more key pecks with interresponse times ranging from 28 to 42 s. These interresponse times did not differ depending on the RI schedule, nor did they bear any obvious relation to those of the baseline sessions. If a peck failed to produce food within 2 to 3 min, the birds usually then paused long enough to meet the DRO requirement. In the open economy, behavior never changed between the end of one feeding opportunity and the start of the next. Runs of food deliveries from the RI schedule displayed response rates like those of the baseline RI schedules. Runs involving the DRO schedule displayed continuous pausing.

Replications never produced Dixon-Mood DRO means that differed by more than 10%. Figure 10 shows the average of the two seven-session means. In the closed economy, as in Experiment 2, mean DRO value varied over a small range. In the open economy, as in Experiment 1, it rose with longer RI values, and power functions fit between DRO and RI values had exponents of 0.61 for Bird 118 and 0.46 for Bird 187. The prevailing DRO always was within an 8-s range of the mean value in the open economy and was within a 4-s range in the closed economy.

In the closed economy, the bird controlled the number of feeder cycles per feeding op-

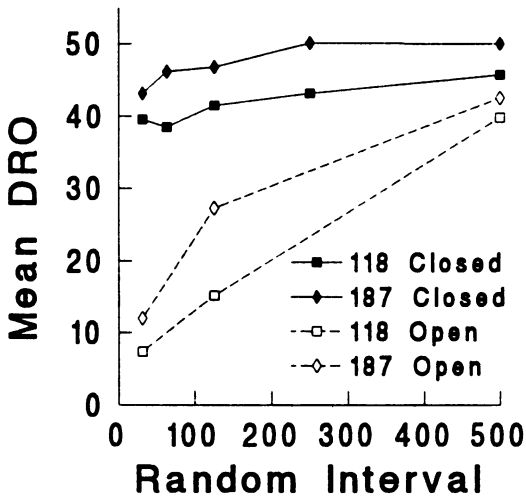


Fig. 10. Mean DRO value in the closed and open economies with DRO and RI schedules imposed together (Experiment 3).

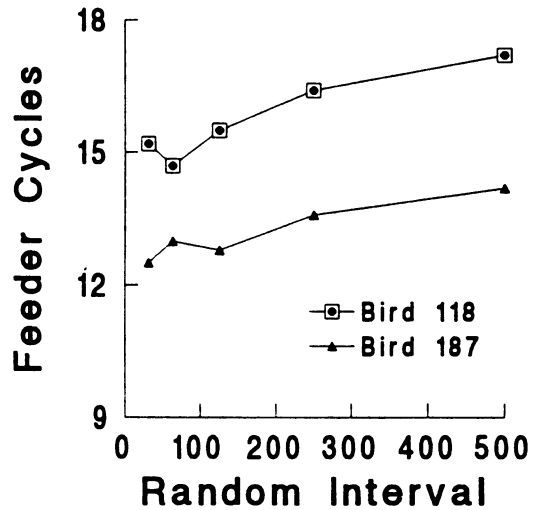


Fig. 11. Mean feeder cycles per feeding opportunity in the closed economy.

portunity. The greatest number of cycles was always in the first feeding opportunity of each session, and that feeding was always obtained via the RI schedule. The number of cycles in this first feeding ranged from 42 to 76.

Figure 11 shows mean feeder cycles per food bout after the first. Cycles per bout varied from 0 to 30 to 35 in all conditions. Bout length seemed unrelated to time since the last feeding or to whether feeding occurred via RI or DRO, but it tended to increase with longer RI schedules. Casual observation suggested that birds did not always eat during a cycle caused by either source, and yet initiated a new cycle when the previous one ended.

Average body weights were 491 g (Bird 118) and 414 g (Bird 187) in the open economy. They ranged around 620 g (Bird 118) and 516 g (Bird 187) in all closed-economy conditions.

#### DISCUSSION

The closed economy produced behavior in pigeons more like that of humans than of pigeons in an open economy. As with humans in Experiment 2, pigeons in the closed economy alternated at random between payoffs obtained for responding and those obtained for waiting without responding. Like humans, pigeons seemed to probe for payoff from the RI and then paused long enough to meet the DRO requirement. Pigeons and humans both kept

the DRO value at a level somewhat longer than that of the average interresponse time. These patterns may not have been perfectly optimal, but they did eliminate the longest interfood intervals arranged by the RI schedule. In contrast, the birds experienced the full range of RI interfood intervals in the open economy. Extended runs of food deliveries occurred from each source. During these runs, response rate was the same as in the baseline RI schedule or no responses occurred at all. In the open economy, the birds got food equally often from waiting and responding only when waiting provided food much faster. The only bias in the closed economy was that the first food delivery of each session always came from pecking.

Behavior also varied with the economy when the RI schedules were in effect alone. Response rate in the open economy showed the decrease with lower frequency of food typical of such schedules (Catania & Reynolds, 1968). The reversed curve in the closed economy derived from two sources. First, the longest interresponse times always occurred after food delivery. Second, times between later responses were about the same with all RI schedules. Given that shorter schedules meant more food deliveries per unit time, more long initial interresponse times occurred as well. The net effect was the monotonically increasing overall response rate.

## GENERAL DISCUSSION

Collier (1983) emphasized that food-deprived animals work in the context of strong immediate need for food. Pigeons in the closed economy operated close to their free-feeding weights, and food was plentiful when found. When food level is low and severely restricted, it seems reasonable for natural selection to favor animals that are strongly biased in favor of actively searching for new resources. The open economy corresponds to such an evolutionary scenario. Overcoming that bias requires a different feeding ecology. One relevant change is for waiting to provide food considerably more frequently than does active search. Under conditions of relative plenty, biases for active search for new sources of food could be less pronounced or may even disappear. That is the case in the closed economy. Such a conceptualization follows both from behavior systems theory (Timberlake & Lucas, 1989) and from Killeen's (1992) argument that drives are the fundamental forces in behavior. Either perspective implies that level of food deprivation, together with conditions of food availability, play an important role in selecting and guiding ongoing foraging patterns.

The data suggested that pigeons performed optimally with respect to food acquisition when they were not food deprived and were able to eat freely at each feeding opportunity. Neither active responding nor waiting without responding were then the preferred strategies used in searching for food. The two strategies were used interchangeably, depending roughly on which had higher potential for yielding food faster at particular times. At first glance, this might seem counterintuitive, because food-deprived animals perhaps should be the most prone to maximize food acquisition. What this intuition overlooks is that food deprivation and limited food availability may cause animals to leave their present environment. In nature they would leave. In the laboratory they cannot. The need to find a new source of food may bring factors into play that preclude maximizing food acquisition under highly controlled laboratory feeding conditions.

Much that characterized the behavior of pigeons in the closed economy also described that of humans. The absence of urgent survival demands perhaps explains why the closed

economy led to behavior of pigeons like that of humans both here and elsewhere (Zeiler, 1991). That pigeons obtained all of their food in the experiment in the closed economy, whereas the humans did not get anything important, must have played some differentiating role, but the overall similarities can be attributed to motivational factors in both cases. Humans in an experimental situation have no biologically significant needs met by their behavior, nor are they under any state of need (except perhaps to escape from the experiment). An obvious gap is the absence of human data under the kinds of immediately pressing biological needs confronted by food-deprived pigeons that receive only tiny portions of food at each feeding. Given the option of responding or waiting for food, humans living at 80% of their normal weights and obtaining a few bites of food at a time might be as biased for active search as were pigeons in the open economy.

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