Effects of effort requirements on video icon choice

Andrew J. Velkey
The University of Montana

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The Effects of Effort Requirements on Video Icon Choice

by

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B.S., Millsaps College, 1991

Presented in partial fulfillment of the requirements for the degree of Master of Arts University of Montana 1995

Approved by

Chairperson

Dean, Graduate School

Date

June 5, 1995
An experiment was conducted in which choices for various effort requirements were examined. It was hypothesized that the lowest effort condition possible would be selected in any given choice situation. Subjects were four, adult Rhesus macaques (Macaca mulatta) with some prior video experience but naive to effort manipulations. Subjects foraged in a computer-generated video environment on an analog joystick which allowed for measurement of sub- and supra-threshold responding with effort defined as the tangential force applied to the end of the joystick (e.g., 0.9, 2.7, and 4.1 Kg). Subjects made choices among pairings of icons representing the three levels of effort. Each subject experienced a corresponding level of effort following a choice condition. The results, as a whole, indicate the effort requirements were discriminable to the subjects as all subjects reliably chose the lowest effort condition possible in any given pairing. Supra-threshold responding was greatest in the low-effort condition and sub-threshold responding was greatest in the high-effort condition. Subjects' responses closely corresponded with the requirements in the medium-effort condition. These results indicate that researchers investigating the effects of effort requirements on behavior should include sub- and supra-threshold responding in their preparations. These findings demonstrate the ability of Rhesus monkeys to make reliable choices based on effort.
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The Effects of Effort Requirements on Video Icon Choice

Optimal foraging theory proposes a set of general principles which seeks to describe the manner in which animals forage for food. An animal is said to behave in an optimal manner if it minimizes its exposure to undesired conditions (hunger, predation, wait states, etc.) and/or maximizes its exposure to desirable conditions (consumption, mating, rest, etc.). From an evolutionary perspective animals should behave in an optimal manner. There are several ways in which one can look at the minimization of exposure or maximization of utilization animals engage in.

The basic assumptions of optimal foraging from Pyke's (1984) review of optimal foraging theory are:

- Animals will behave in a manner which minimizes their exposure to predation, environmental hazards, and other potentially lethal situations.
- Animals will inherit a foraging strategy and an animal's fitness is dependent on its foraging.
- This relationship between foraging and fitness is known.
- Environmental and organismic constraints will affect an animal's foraging.
- An animal will forage in a manner which will maximize its net caloric intake.

Caloric Optimization

The final assumption is one of interest, for it suggests that animals will modify their activities to minimize net caloric expenditure. In most studies, it is
prohibitively intrusive to attempt to measure caloric expenditure directly through physiometric measures. However, one can make an argument for relating effortful responding to caloric expenditure. This argument carries an assumption that the greater the effort expended by an animal, the greater the caloric expenditure in that effortful activity. The other assumption is that an animal will choose foraging which results in the greatest net caloric gain for that animal. Studies of effort may be helpful in considering the effects of effort requirements on the behavior of a foraging animal.

One factor which affects the behavior of animal subjects is the magnitude and quantity of responding which is required for reinforcement. This can be thought of as effort. The effects of effort requirements on responding are not clearly understood. Increased effort requirements may result in either: A) increased rates of responding (e.g. Lewis, 1964), B) decreased rates of responding (e.g. Collier, Hirsch, Levitsky, Leshner, 1973; Skinner and Morse, 1958, Aiken, 1957), or C) no effect on rates of responding (e.g. Applezweig, 1951; Gollub and Lee, 1966).

For example, Lewis (1964) found that female rats would consume more reinforcers and run faster towards the goal box in a runway if they were harnessed to a cart with greater resistance to moving. In his experiments, rats in the low-effort (LE) group were harnessed to a weight of 5-gm and
rats in the high-effort (HE) group were harnessed to a weight of 80-gm. The HE group rats ran faster to the goal box in a runway, ate faster, and ate more reinforcers in a separate ad-lib setting than their LE group counterparts.

Based on these findings, Lewis proposed several interpretations. The first was based on cognitive dissonance. An organism in a high-effort situation may not receive sufficient reward from its effortful activity. In this situation, the organism would either discontinue its responding or attribute a higher value to that reinforcer. This increased preference may reduce dissonance for the organism. Another interpretation offered is based on frustration. High-effort requirements increased the drive level and therefore resulted in the greater reinforcement value of reducing that drive level. Lewis's third interpretation was interesting; the proprioceptive stimuli associated with a higher effort condition may be more intense and their increased discriminative properties may have increased the value of the original reinforcer. This increased value would result in greater rates of responding and faster consumption of the reinforcer. Finally, Lewis suggested that perhaps the technique of fastening a harness with a high-weight condition not only produces more effortful responding, but also reduces non-goal directed behavior. The act of attaching a high-weight harness to the rat resulted in the rat attending more to pulling the weight
and directing behavior towards the goal box.

However, other investigators have found that increased effort conditions can result in lower rates of responding. Collier, et al, (1973) found that increased effort conditions resulted in lower rates of behavior of spontaneous activity. Rats were required to run in either variably braked Wahman running wheels or on a motorized belt at various inclinations. The investigators found that rats would run shorter distances and for shorter periods of time at the increased effort levels. The investigators suggested that the rat behaves in a manner which is not consistent with a work invariance hypothesis; that is, regardless of effort requirements, the total work done by an animal in any situation will be constant. Furthermore, the investigators suggested, at least for spontaneous activity, effort is aversive.

Other studies have shown that effort may have no effect on rates of responding. Applezweig (1951) found that rats would perform at the same rate in a high-effort condition as in a low-effort condition. Rats were trained to press levers of varying degrees of tangential force (TF) requirements. After a period of learning, the high TF rats pressed levers at the same rate as low TF rats. However, effort did have an effect on the rate of acquisition of the learned response. The higher the effort level, the greater the chance for failure to learn and the longer it took for
the rat to learn the response. Effort also had an effect on extinction, with the increased effort conditions resulting in more rapid extinction of the learned response. Similar findings are reported by Lewis (1964). Obviously, much more study must be done with effortful tasks to determine how effort requirements affect the responding of animals in the experimental setting.

The caloric expenditure of a foraging activity will affect the choices an animal will make if it is to forage in an optimal manner. If the caloric value of an exclusive prey object is held constant and the handling time is not varied, the animal should respond more often in the low-effort condition (Keehn, 1981). However, as illustrated in the previous discussion, the effects of effort on the behavior of animals are not clearly understood.

**Time Optimization**

Because of the difficulty in obtaining valid measures of caloric expenditure, many investigators have chosen to focus on another prominent component of foraging models, namely time minimization. Time minimization is a key component to almost all optimal foraging models. Using operant paradigms, many investigators have examined time minimization by employing two or more concurrent schedules from which the subjects could choose.

Hernstein (1970) offers a model, the matching law,
which simply states that, given two or more concurrent
schedules of reinforcement, the relative rate of responding
on an alternative will match the relative rate of
reinforcement for that alternative. This matching not only
applies to rates of reinforcement, but also to the relative
magnitude of reinforcement (Fantino, 1987), and to the
relative delay to reinforcement (Chung and Hernstein, 1967).

Rachlin and Green (1972) set out to determine how the
matching law would apply in a self-control setting. If
pigeons had the option to peck on a red key that provided
immediate access to grain for two seconds or to peck on a
green key that provided a four-second delay before access to
grain for four seconds, the pigeons would reliably choose
the smaller, but more immediate, reward. This concurs with
the matching law. Furthermore, if the investigators delayed
access to the food keys by a fixed ratio 15 requirement for
access to either of the food keys with a ten-second delay to
food key access, the pigeons chose the greater, but more
delayed, reward in approximately sixty percent of all
trials. This outcome is also explained by matching law:

\[
\frac{\text{Pecks on Green}}{\text{Pecks on Red} + \text{Pecks on Green}} = \frac{4}{10s + 4s + 4s + 2s} = 0.60
\]

Mazur and Logue (1978) had similar findings. The
investigators faded the delay to delivery of the small
reinforcer from six to zero seconds. As the delay
approached three seconds, the pigeons began to select the
small reinforcer (two-second access to grain) over the large reinforcer (six-second access to grain). However, the subjects never demonstrated exclusive preference for the smaller reinforcement, as would have been predicted from an impulsiveness model.

However, Logue, Chavarro, Rachlin, and Reeder (1988) found support for an impulsiveness model with pigeons in an attempt to discern the ecological validity of self-control paradigms. In four separate conditions, pigeons were able to choose between a larger, more delayed reward and a small, less delayed reward. In the first condition, the pigeons were food-deprived to maintain 80% of their free-feeding weight and tested every four days. In the second condition, the pigeons had ad-lib access to food at all times and were tested every four days. In the third condition, the pigeons were free-fed and tested every day. In the fourth condition, the reinforcement rate was much less frequent. In all conditions, the pigeons lived in the experimental chamber and experienced a session length of twenty-three hours. In spite of this attempt to make the setting more "natural", the pigeons still behaved in an impulsive manner; they still chose the smaller, more immediate reward. This finding argues for the sensitivity of pigeons to pre-reinforcer delay.

Logue, Smith, and Rachlin (1985) found that pigeons were most sensitive to pre-reinforcer delays and would
behave in a manner which reduces this delay even if overall access to reinforcement is decreased. However, the pigeons would nearly maximize their responding (and subsequent uptake) if delay for both was equal but one choice led to access to food for a longer time than the other choice. The subjects were much less sensitive to postreinforcer delays and rate of reinforcer access. Obviously, it can be seen that a subject's sensitivity to time minimization is quite dependent on the presence (or absence) of various stimuli in the environment (Grosch and Nueringer, 1981), the magnitude of the reward (Logue, Smith, and Rachlin, 1985), and the subjective quality of the reward (Mischel, 1974).

Fantino (1987) develops a view of time minimization with the delay reduction hypothesis. Within the delay reduction hypothesis framework, the stimulus which indicates a greater reduction in time to food obtainment will be chosen more readily over a stimulus which indicates a lesser reduction in time to food obtainment, i.e. a foraging model of time minimization based on Hernstein's matching law. Fantino modified Lea's (1979) procedure and trained pigeons to make active choices between two variable interval (VI) schedules. The pigeons would reliably reject a VI 20-second schedule over a VI 5-second schedule in a delayed-choice preparation. According to Fantino's results, it would appear that pigeons are sensitive to the amount of time that passes between reinforcers and will optimize that time as
much as possible. Lea (1979) trained pigeons to peck on an intelligence panel with a choice between fixed interval (FI) schedules of either 5 or 20 seconds. The subjects reliably chose the FI 5-second schedule and rejected the FI 20-second schedule in a manner which qualitatively (but not quantitatively) agrees with optimal foraging theory. This would indicate that pigeons are sensitive to stimuli which reduce the amount of time spent waiting for food.

This time minimization is sensitive to several variables, including quality or magnitude of the reward and delay to reward upon completion of the operant. Grosch and Neuringer (1981) found that pigeons could be taught to wait for the delayed but more preferred food type in a variety of conditions. Pigeons would reliably choose a delayed, but more preferred, reinforcer type under any of the following conditions:

- If the reinforcer were not visible.
- An alternative response manipulanda was present.
- Stimuli correlated with the reinforcer were absent.
- A stimuli associated with positive consequence was present.
- The subject had engaged in consummatory behavior just prior to the delay period.
- Previous self-control had not been punished.
- Higher rates of responding were required during the waiting period.
Obviously, many factors affect the strategies a subject will utilize in a given foraging session.

**Distance Minimization**

Another way to discern the optimality of an animal's behavior is to examine the travel path(s) utilized by a foraging animal for minimization. If an animal selects paths to reinforcers which are minimal with respect to total distance traveled, it may be that the animal is working under a distance minimization strategy. For instance, MacDonald and Wilkie (1990) found that yellow-nosed monkeys were efficient foragers in that the subjects tended to optimize the distance traveled between baited food cups. The monkeys were trained first to visit all of eight food cups (which were baited) in the experimental enclosure. The second phase had the male monkey first visit all eight food cups (four of which were baited), the monkey was removed, the four cups which were not baited were then baited, and the monkey was released into the enclosure. The monkey reliably adopted a "win-shift" strategy of minimizing movement to empty cups and a minimal path between baited cups. The third phase had both monkeys adopting a "win-stay" strategy where the four cups that were previously baited were again baited. The animals reliably adopted this strategy and also minimized exposure to unbaited cups as well as minimizing the path between paths.
In a similar manner, Cramer (1994) found that vervet monkeys which were allowed to observe the baiting of four to eight (of twenty-five) food cups in an outdoor enclosure reliably gathered up to six reinforcers. Furthermore, the monkeys' paths were nearly optimal in minimizing the total distance travelled in gathering reinforcers. This supported a "look-ahead" strategy in which the monkey went to a baited food cup, consumed the reinforcer, then traveled to the next baited food cup that would optimize its overall route (not necessarily the next closest baited food cup).

Mellgren and Misasi (1984) also suggest that travel costs, which include distance traveled, will affect the optimal strategy of rats. In their study, rats were allowed to forage in sand patches which were reached by climbing nail ladders. Along with patch density variation, distance traveled to the patch was varied. Animals which had to travel a greater distance spent more time depleting a food patch.

As can be seen in the above examples, several variables exist which animals may or may not optimize. Pyke (1978) utilizes a mathematical model to determine whether bumblebees move from nectar source to nectar source in an optimal manner. Pyke assumes in this model the variable the animals are optimizing is net energy gain in a foraging bout as it relates to both the time taken visiting resource points and the time spent moving between resource points.
It was found that the bumblebees behaved in a manner which closely fit this mathematical model.

In another study, Pyke (1981) examines the optimal travel speeds of animals in another mathematical model:

\[ E = e_t T_f - [c_h(v) T_a + C_0(t)] \]

In this model, the overall net energy gain available to a foraging animal (E) is defined in terms of energy gains from foraging \( e_t \) multiplied by the time spent foraging \( T_f \), minus the rate of energy expenditure during non-foraging activity \( c_h(v) \) multiplied by the amount of time spent in that non-foraging activity \( T_a \) added to the energy expenditure during the time spent in other activity \( C_0(t) \). In other words, Pyke's model relates net energy gain with the energy gain associated with a foraging bout less the energy loss from non-foraging activities.

On the other hand, other investigators suggest animals will optimize their movement as it relates to the distance which the animals cover in a foraging bout. MacDonald and Wilkie (1990) examined the travel paths of their animal subject's with respect to a least-distance algorithm in spatial-memory tasks. This is also supported by Cramer (1994) who suggests an optimal "look-ahead" algorithm in another spatial-memory task.

There is an obvious confound present in such a univariate approach to optimal foraging studies: generally speaking, the least-distance path to a prey object is also
the least-time path. Most animal species forage mainly in a two-dimensional plane, either by active movement within that plane (e.g. four-legged mammals) or by scanning the two-dimensional plane from above (e.g. avian species). The question remains; which do animals optimize, time or distance?

Szalda (1992) examined distance versus time solutions using rhesus monkeys foraging in a computer-generated video environment. In this environment, the cursor (under control of the subject via a digital joystick) could have one of two speeds on the screen. Speed was dependent on which area of the screen the cursor was located. The fast medium was only that horizontal portion of the screen where the cursor was initialized. The cursor could either be moved laterally in this medium and then straight down (through the slow medium) to the prey object or moved diagonally to the prey object entirely through the slow medium. One subject appeared to utilize a distance-optimization strategy and the other appeared to utilize a time-optimization strategy. The investigator discussed several reasons why the individualist results were reached. The subject which did not utilize the minimal-time solution may have been overexposed to the diagonal solution or it may have very well been that the animal was actively choosing an optimal distance solution.

Szalda-Petree, Szalda-Petree, and Velkey (1994) attempted to apply more controls to the above design by
including two more subjects, re-defining the fast medium to include a path across and up to the prey object so the cursor could be maintained in the fast medium during the entire path and expanding the differential between the time and distance solutions to ten and twenty seconds. The results of the study were much more discernable than those of Szalda (1992). The two females included in the study were much more sensitive to time optimization and readily chose that solution when available. However, the females maintained the optimal time path even when the quicker time would have been to travel along the diagonal. The males were much more persistent in their use of the optimal distance solution, only utilizing the optimal time solution near the end of the experiment after hundreds of exposures to the fast medium. It is apparent that more study must be done in an analysis of optimization examining time, distance, and caloric solutions.

In the present experiment, effort choices were examined with rhesus monkeys using a video icon selection task. Effort was defined as the tangential force necessary to pull an analog joystick either left or right. The subjects were given choices between three different levels of effort: low, medium, and high, which were determined during joystick shaping. Low effort was 3 units of force (UOF), approx 0.9 Kg of tangential force (TF) applied to the end of the joystick. Medium effort was 8, 10, or 15 UOF (15 UOF is
approximately 2.7 Kg of TF). High effort was 13, 18, or 23 UOF (23 UOF is approximately 4.1 Kg of TF).

It was hypothesized that the subjects would reliably choose the "least-effort" solution. How sensitive the subjects were to the continuum of force requirements was unknown. However, it was expected that the subjects would reliably choose the low-effort solution over the high-effort solution, based on the "least-effort" findings of Collier, et al (1973) and Keehn (1981). This finding would also support the optimality model proposed by Pyke (1984). Subjects were also expected to take a longer period of time to complete foraging in the medium and high effort conditions, based on the findings of Brooks (1994) and Karkowski (1994).

Method

Subjects

Four adult rhesus monkeys (Macaca mulatta), ages 7.5 to 10 years, were used from the primate social colony at the University of Montana. Two males (Bud and Vern) and two females (Peeper and Pansy) with some prior experience with video tasks were selected. However, none had any experience with differential effort experiments. They were housed individually for the entire length of the experiment and had ad-lib access to water at all times and ad-lib access to food except during experimental sessions.
Apparatus

The testing chamber was the monkey's home cage (61 cm X 92 cm X 61 cm) with a cart attached via lock-down cables. The cart contained a video monitor, analog joystick, feeder, and a video camera. The monitor was placed approximately 15 cm from the face of the cage with the joystick centered beneath the monitor. Reinforcers consisted of a mix of "Kix" and "Fruit Whirls" cold cereal in a 3:1 ratio, respectively. A feeder dispensed reinforcers to a bin located below the joystick. The monkeys were monitored via a video camera installed on top of the cart and directed at a mirror angled over the home cage (testing chamber). Force applied to the end of the joystick forced a bar down onto a spring, as the spring compressed, a potentiometer rotated thus indexing the amount of force applied to the joystick.

An IBM-compatible computer was programmed to read the setting of the potentiometer via an analog-to-digital conversion card, provide the video image the subjects view, and control the feeder mechanisms via relay cards. The program also collected data in one-second bins and stored that information to disk.

Procedure

Joystick Shaping Phase, Days a-d, 1-9:

This phase was necessary to train the subjects to respond on the joystick and to become familiar with force
requirements for cursor movement. Each subject was presented with a horizontal "alley" on the screen approximately three times the height of the cursor and prey box with length being the full width of the video screen. The cursor initially appeared on one end of the alley with the red prey box at the opposing end. The initial position of the cursor was randomly assigned with the stipulation that no more than three trials began with the cursor in the same position. There was no effort requirement beyond the minimum necessary to register movement of the joystick (3 UOF) for the first 4 days of shaping (days a-d) or the first two days of activity (days 1 and 2). The force requirement was as follows: UOF for days 3, 4, and 5 was 5, UOF for days 6 and 7 was 7, and UOF for days 8 and 9 was 10. For days 1 through 9, data was collected on the forces exerted on the joystick for determination of the force requirements for the choice phases.

The subject manipulated the joystick in the direction of the prey box to move the cursor in the same direction. The cursor moved at a speed which resulted in a minimum of ten seconds to cross the screen and contact the prey box. Once the cursor contacted the prey box, a reinforcer was delivered and an inter-trial interval (ITI) of two seconds began. Each session consisted of sixty trials. When all subjects had completed their sessions in less than two hours on two consecutive days, the icon shaping phase began.
Icon Shaping, Days 10-12:

Icon shaping was necessary to train the subjects to move the cursor into contact with a force icon. The force icons programmed were three times the size of the cursor and the prey box, and they were triangles of three different VGA colors: BLUE, GREEN, and YELLOW. There was no effort requirement beyond the minimum necessary to register movement of the joystick (3 UOF). A black screen was presented with the cursor in the middle and a force icon positioned at either the left or the right of the screen. The positioning and the icon color were randomly assigned with the stipulation that the same icon position and color occurred no more than three times consecutively. The subject moved the cursor into contact with the force icon for delivery of a reinforcer. Reinforcement was followed by a two-second ITI. When all subjects selected sixty force icons in less than two hours on two consecutive days, the choice phases began.

Choice Phase Ia, Days 13-21:

In choice phase Ia, the subjects moved the cursor into contact with a force icon on the choice screen. The choice screen consisted of a black background presented with the cursor in the middle and a pair of icons, one on each side of the cursor. Each pair of icons was presented in blocks of twenty consecutive pairings, resulting in all possible
pairings being exhausted in three blocks of twenty for a session length of sixty trials. The ordering of the blocks was randomized for each day.

After an icon had been contacted by the cursor, the choice screen was erased and the foraging screen was displayed. The foraging screen consisted of the alley presented with the cursor at one end and the prey box at the opposite end. The positioning of the cursor was randomly determined with the constraint that not more than three consecutive trials began from the same start position. The movement of the cursor occurred only if the subject pulled the joystick past the effort threshold associated with the color of the icon selected, which was 3 UOF for BLUE, 8 UOF for GREEN, and 13 UOF for YELLOW.

Cursor contact with the red prey box resulted in the delivery of a reinforcer. Latency to icon choice, forces exerted during icon selection, latency to prey box, and forces exerted during foraging were recorded in one-second bins.

**Choice Phase Ib, Days 22-38:**

Choice phase Ib was similar to choice phase Ia, except the effort associated with GREEN and YELLOW was increased to 10 UOF and 18 UOF, respectively. The effort levels were increased in an attempt to make the effort conditions more discriminable.
Choice Phase Ic, Days 39-56:

Choice phase Ic was similar to choice phase Ia and choice phase Ib, except the effort associated with GREEN and YELLOW was increased to 15 UOF and 23 UOF, respectively, since the subjects were still not discriminating between effort levels.

Choice Phase II, Days 57-67:

In choice phase II, the block length was increased to sixty trials, each session consisting of a single block. This was done to present subjects with a larger amount of exposure to each icon pairing within the daily session. All possible pairings of icons were exhausted over three sessions before being randomized and exhausted over the next three sessions. The effort levels remained the same.

Choice Phase III, Days 68-80:

Since a large expanse of time often elapsed between icon choice and trial completion (and the subjects may not have retained the icon they chose over that period of time), the video presentation in choice phase III was modified to a "split screen" display. The top half of the screen contained the cursor and the two icons with an empty alley in the bottom half. When the cursor contacted an icon, the unselected icon was erased and the cursor and prey box
appeared at opposite ends in the alley below. During the foraging portion of the trial, the selected icon remained where it was selected in the upper half of the display. Block length remained at sixty trials and the force levels were unchanged.

Choice Phase IV, Days 81-96:

In the final phase, the split-screen procedure and force levels were retained from choice phase V, but the block length was decreased to twenty trials with a session consisting of three blocks again. This was done to give subjects exposure to all icon pairings within each daily session.

Table 1 reviews the icon force level, blocking, and display for each choice phase.

<table>
<thead>
<tr>
<th>PHASE</th>
<th>ICON FORCE REQUIREMENT</th>
<th>BLOCK SIZE</th>
<th>CHOICE AND FORAGE SCREENS</th>
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<tbody>
<tr>
<td>Ia</td>
<td>3, 8, 13</td>
<td>20</td>
<td>separate</td>
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<tr>
<td>Ib</td>
<td>3, 10, 18</td>
<td>20</td>
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</tr>
<tr>
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<td>3, 15, 23</td>
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<td>same</td>
</tr>
<tr>
<td>IV</td>
<td>3, 15, 23</td>
<td>20</td>
<td>same</td>
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</tbody>
</table>

Table 1: Review of choice phase parameters
Results

Four dependent measures were calculated: icon selection percentages, trials to criterion, average force outputs, and average median forage times. All calculations were across Phases Ic through IV, except trials to criterion, which was calculated from the start of Phase Ia through completion by the subject. The icon selection percentages were calculated for the three days of stability for each animal and are displayed in Table 2. The values for trials to criterion were calculated across the number of number of daily sessions each subject experienced and are displayed in Table 3. The average and standard deviation of the force outputs across each phase for each animal were calculated and are displayed in Table 4. The median time to completion was calculated for each trial and the averages and standard deviations of these values for each animal at each effort level are displayed in Table 5.

Icon Selection Percentages

<table>
<thead>
<tr>
<th>Selection Percent</th>
<th>Low over Medium</th>
<th>Medium over High</th>
<th>Low over High</th>
<th>Average lower force icon selected</th>
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<tr>
<td>Bud</td>
<td>95</td>
<td>93</td>
<td>100</td>
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<td>Vern</td>
<td>100</td>
<td>83</td>
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<td>94</td>
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<tr>
<td>Peeper</td>
<td>100</td>
<td>93</td>
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<td>Pansy</td>
<td>100</td>
<td>100</td>
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</table>

Table 2: Icon Selection Percentages at Stability
As can be seen in Table 2, all subjects were able to reliably select the lower force icon in 83%-100% of all presentations. Every subject reliably selected the low force icon over the high force icon in every presentation with no variation. Low over medium force icon selection was also quite stable. The most variable selection was that of medium over high; only Pansy was able to select medium over high force icons 100% of the time. Overall, the subjects were able to reliably choose the lower force icon in 94%-100% of all trials once criterion was met.

Trials to Criterion

<table>
<thead>
<tr>
<th>Effort Comparisons</th>
<th>Low vs High</th>
<th>Low vs Medium</th>
<th>Medium vs High</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUD</td>
<td>400</td>
<td>420</td>
<td>620</td>
</tr>
<tr>
<td>VERN</td>
<td>1720</td>
<td>1780</td>
<td>1840</td>
</tr>
<tr>
<td>PEEPER</td>
<td>1360</td>
<td>1480</td>
<td>1780</td>
</tr>
<tr>
<td>PANSY</td>
<td>1480</td>
<td>1480</td>
<td>1560</td>
</tr>
</tbody>
</table>

Table 3. Trials to Criterion

All subjects were first able to reliably choose the low effort icon when paired with the high effort icon. The next discrimination all subjects learned was the low effort icon paired with the medium effort icon. Lastly, the subjects learned to choose the medium effort icon over the high effort icon. Bud's choices reached criterion by the end of Phase Ic. All other subjects' choices reached criterion by
the end of Phase IV.

**Mean Force Outputs**

<table>
<thead>
<tr>
<th></th>
<th>Effort Level</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOW</td>
<td>MEDIUM</td>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>BUD</td>
<td>7.83 (.49)</td>
<td>16.68 (.56)</td>
<td>22.54 (1.23)</td>
<td></td>
</tr>
<tr>
<td>VERN</td>
<td>12.91 (1.87)</td>
<td>18.15 (.89)</td>
<td>23.55 (.99)</td>
<td></td>
</tr>
<tr>
<td>PEEPER</td>
<td>5.62 (1.00)</td>
<td>16.05 (.86)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PANSY</td>
<td>9.55 (2.60)</td>
<td>18.27 (1.13)</td>
<td>22.55 (2.14)</td>
<td></td>
</tr>
</tbody>
</table>

Standard deviations in parentheses

Table 4. Mean Force Outputs (in UOF)

As can be seen in Table 4, all subjects clearly demonstrated the ability to meet the force requirements at all effort levels. Variation of output is lowest at the medium effort level, and variation of output is higher at the low and high effort conditions (except Bud in the low effort condition). All subjects exerted much more force than necessary in the low effort condition; the requirement was only 3 UOF. All subjects had a mean output over the requirement of 15 UOF in the medium effort condition, exertion above this requirement was not as pronounced. Sub-threshold responding was greatest in the high effort condition; only one subject had an average output above the requirement of 23 UOF in the high effort condition.
Average Median Foraging Times

<table>
<thead>
<tr>
<th>Effort Level</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUD</td>
<td>11.60</td>
<td>16.00</td>
<td>27.30</td>
</tr>
<tr>
<td>VERN</td>
<td>11.20</td>
<td>13.70</td>
<td>19.70</td>
</tr>
<tr>
<td>PEEPER</td>
<td>12.80</td>
<td>25.90</td>
<td>84.20</td>
</tr>
<tr>
<td>PANSY</td>
<td>11.70</td>
<td>14.70</td>
<td>28.70</td>
</tr>
</tbody>
</table>

Standard Deviations in parentheses

Table 5. Average Median Foraging Times (in seconds)

Median times were calculated in comparison to average times due to the non-normal distribution of latencies seen in all effort conditions. All subjects were able to complete foraging in a relatively rapid manner in the low-effort condition. The minimum possible time to completion was approximately 10 seconds; all subjects were able to complete a foraging run in 11.2 to 12.80 seconds on average in the low-effort condition. Time to completion for the medium-effort condition was slightly slower (13.7 to 25.90 seconds) and slightly more variable. Time to completion was considerably longer for the high-effort condition (19.70 to 84.20 seconds) and much more variable.

Discussion

The results indicate the force requirements of 3, 15,
and 23 UOF (0.9, 2.7, and 4.1 Kg of TF) are discriminable by all subjects. Subjects' force outputs correspond with the force requirements of all effort levels. The subjects' ability to discriminate effort levels is also quite evident in the subjects' ability to actively choose the lowest effort condition possible in any paired presentation.

All subjects clearly demonstrated the ability to select the lowest effort condition in all pairings. Selection of the low-effort icon over the high-effort icon was the most pronounced; this is likely due to the high level of discrimination between the two effort levels. Low-effort icon selection over the medium-effort icon was the second-most pronounced. Medium-effort icon selection over high-effort icon is the least pronounced of the three comparisons. There are at least two explanations for this. First, the differentiation between these two levels of effort is not as pronounced, and therefore not as discriminable. Secondly, the selection of the medium-effort icon may have represented an "approach/avoidance" problem to the subjects. In the medium-effort/high-effort icon pairings, the subjects had to learn to approach the medium effort icon to select the lowest effort condition. However, in the low-effort/medium-effort icon pairings, the subjects had to learn to avoid the medium effort icon in order to optimize. It appears to have been more difficult for the subjects to learn when to select the medium-effort icon.
As effort levels increased, the amount of time the subjects took to complete a foraging bout increased as predicted. This is most pronounced in the high-effort condition. The time subjects took to complete foraging in the medium-effort condition was only marginally greater than in the low-effort condition, and possibly no different for the experience of two of the subjects. If a subject responded at or above threshold continuously, there would be no difference in forage times. The increase in forage times is a result of both increased sub-threshold responding and increased non-foraging responses during foraging bouts.

The subjects' output was most stable about the medium effort requirement. Although the subjects, on the whole, expended slightly more effort than needed, this output was fairly stable. In the high effort condition, almost all subjects' responses had a mean output below the requirement, and all had increased variability. This increased variation is mainly due to sub-threshold responding. Obviously, the subjects had to be capable of the high-effort response in order to receive reinforcement and continue with the next trial, so some supra-threshold responding also contributed to this variation. The subjects' mean output far exceeded the requirement necessary in the low-effort condition. High variation in response in the low-effort condition is due to pronounced supra-threshold responding. The overall appearance of the response output variability curve (a "U")
shape) may be due to an anchor at the medium-effort level and a function of the relationship of medium-effort to both low- and high-effort conditions.

Much more interesting, however, is the amount of supra-threshold responding in the low-effort condition. Although a low-effort condition may exist, the results indicate subjects often respond at a much higher level. This has definite implications for the future study of effortful responding and optimal foraging theory. First, if an experimenter utilizes only a low-effort condition and defines effort as a function of instantaneous responses (i.e., bar presses and/or key pecks), incomplete models may be most predictive. Brooks (1994) found that rats responding in a running wheel responded differently in high-effort conditions in comparison with high-cost conditions. Increases in effort, defined as the tangential force required to turn the wheel, led to a decrease in actual running speeds, while increased response cost (i.e., distance travelled) led to an increase in post-reinforcement pauses instead of a decrease in actual running speeds.

Various interpretations of effort may be the reason why certain researchers in the past have been unable to find effects for effort, but effects for other variables such as time and/or distance. In a low-effort condition, foragers may be more sensitive to time optimization; a model such as Fantino's (1985) Delay Reduction Hypothesis is a good
predictor of choice behavior in this situation. As the effort required to complete a foraging bout increases, however, animals forage in a manner which more closely fits with a model accounting for caloric gains from foraging activity as it relates to accumulations (prey capture) vs losses (pursuit responses) per unit of time (i.e., a net caloric expenditure model).

Lea (1979) proposed conditions in which the net energy gain per unit of time should be selected by an optimal forager. In a given foraging situation, the animal will choose to pursue and consume a prey object or to reject a prey object. The choice of a prey object will depend on the densities of other prey types. The greater the energy gain from the prey object chosen over that prey object's handling/pursuit time, the greater the overall maximization of net energy gain per unit of time. In essence, Lea defined the choice of a specific prey object in regards to three parameters:

1) The densities of other prey objects in the environment (i.e., distance).
2) The handling/pursuit period of the chosen prey (i.e., time).
3) The caloric gain from the chosen prey (i.e., effort).

If only one prey type of a fixed caloric value were available in an environment and the handling/pursuit time of that prey object were held constant, the optimal forager should always choose the prey object. However, the net caloric gain from pursuit of a prey object can be
manipulated by varying another parameter: effort. Effort can be defined as the expenditure of calories necessary to pursue and consume the prey object. Assuming the relationship of effort to caloric expenditure to be positive and linear, consider an animal which must choose between a high-effort condition and a low-effort condition to obtain the same prey in the same amount of time. If that animal is optimal in its foraging, it follows from Lea's stipulations that the low-effort condition will be chosen over the high-effort condition.

It must be noted, however, that the current preparation contains a methodological confound: manipulation resulting in an increase in effort led to a subsequent increase in the amount of time to complete foraging. Simply stated, as force requirements increased, the time to next reinforcer increased in most conditions. It may very well be that subjects were reacting to the amount of time for completion of a foraging bout by choosing icons which represented the least-time solution to them. However, at the low vs medium effort pairing, the time difference is negligible for two of the subjects and a least-effort solution can be inferred at that level. The difference in mean force outputs from low-effort to medium-effort conditions is 5.24 UOF for Vern and 8.72 UOF for Pansy, whereas the difference in median time to complete foraging is 2.5 seconds for Vern and 3.0 seconds for Pansy.
Furthermore, it can be assumed that the subjects learning of the choices is based on the level of discrimination between each of the conditions. If the subjects were discriminating based on the time to complete a trial, they should have learned to discriminate first the low-effort icon over the high-effort icon (an average difference of 8.5 to 71.4 seconds). They should have next learned to discriminate between the medium-effort icon and the high-effort icon (an average difference of 6.0 to 58.3 seconds). The last discrimination learned should have been between the low-effort icon and the medium-effort icon (an average difference of 2.5 to 13.1 seconds). The subjects' learning based on trials to criterion does not reflect learning based on a "least-time" strategy.

However, the difference between the low-effort condition and the high-effort condition is 20 UOF (approximately 3.2 kg of TF). The difference between the low-effort condition and the medium-effort condition is 12 UOF (approximately 1.8 kg of TF). Finally, the difference between the medium-effort condition and the high-effort condition is 8 UOF (approximately 1.4 kg of TF). The subjects learned their choices following the level of discrimination between the TF requirements in each of the effort conditions. The subjects' learning does reflect learning based on a "least-effort" strategy.

The results demonstrate Rhesus monkeys will reliably
choose the lowest effort condition in a video foraging task. However, due to the increased foraging times found in medium and especially high effort conditions, it cannot be inferred that the subjects' selections are based solely on effort minimization, except in those situations where the foraging completion time for low and medium effort conditions is similar. Future researchers must take this into account, and subsequent preparations should include designs which allow for separation of the effort and time (and distance) variables that affect the choice behavior of optimal foragers. In addition, those preparations which utilize low-effort conditions should also measure supra-threshold responding. Development of optimal foraging theory relies on precise measurement of a multitude of variables and omission of any (such as effort) may lead to unfounded assumptions and development of models which may not accurately predict the behavior of animals in all foraging situations.
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