EFFECTS OF REWARD MAGNITUDE ON KEY PECKING AND EATING BY PIGEONS IN A CLOSED ECONOMY

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Three experiments examined the effects of reward magnitude on key pecking and eating by pigeons in a closed economy. In Experiment 1, one deprived pigeon and two nondeprived pigeons key pecked on increasingly higher fixed ratios to earn access to food for the remainder of the session. In Experiments 2 and 3, deprived pigeons working in a closed economy key pecked on either six fixed-ratio or two variable-interval schedules to earn access to one of three short durations of feeding. All pigeons initially key pecked more frequently as the ratio (or interval) size increased or reward magnitude decreased. In Experiments 1 and 2, the point of maximum key pecking varied directly with magnitude of reward and occurred at similar prices (number of key pecks per gram of food eaten). Key pecking on interval schedules also varied inversely with reward magnitude; however, maximum key pecking was sustained over a wider range of prices. The implications of these results for economic models and regulatory models of learned performance and the concept of ratio strain in a closed economy are briefly discussed.

The concepts of reinforcement, deprivation, and satiation led to standardized operant conditioning procedures. Standard practice dictates, for example, that deprivation ensures food pellets or dippers of water function as reinforcers and limiting the number of reinforcers ensures motivation is held constant by precluding satiation. Even though operant conditioners have established numerous functional relations between parameters of reinforcement and rate of instrumental responding by using standard practices, ethologists and psychologists now question the generality of these functional relations.

Moran (1975) raised the question of ecological relevance. He found little evidence to show that the appetitive behavior of animals in the wild corresponds to the pattern of feeding predicted by a depletion-repletion model. Moran also argued that the functional relations between instrumental responding and feeding or drinking obtained by using the "free behavior" procedure, in which an animal obtains all of its daily food or water, would portray more accurately the behavior of wild animals. He cautioned, however, that these relationships might differ from those obtained in experiments using standard practices.

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Working within the operant tradition, Hursh (1978, 1980) demonstrated that the functional relation between schedule of reinforcement and rate of instrumental responding depends on the type of economy. An open economy is one in which the animal receives only a limited portion of its daily intake, the standard practice, whereas a closed economy is one in which the animal obtains all of its daily intake, the “free behavior” procedure. Hursh also argued that we need to test the generality of the functional relations obtained in experiments using an open economy by performing new experiments using a closed economy. Despite numerous experiments in which pigeons were trained using standard practices, only Lucas (1981) has studied instrumental responding by pigeons in experiments using a “free behavior” procedure or closed economy.

The primary goal of the present three experiments was to determine the functional relations between magnitude of reward and key pecking and eating by pigeons working in a closed economy. The secondary goal was to examine the phenomenon of “ratio strain” which is not well understood even though it occurs in many species, responding for a variety of rewards in experiments that use standard practices (Hogan & Roper, 1978; Timberlake, 1977).

Experiment 1

Ferster and Skinner (1957) and Hogan and Roper (1978) showed that ratio strain occurs when a pigeon must peck 50 to 150 times for a 3- to 4-s hopper presentation during standard sessions. The classic explanation for ratio strain focused on the work requirement. Skinner (1938, 1953) attributed ratio strain to fatigue (abulia), resulting from the large number of responses required to produce a reinforcer, and to extinction, resulting from the repetition of unrewarded responses and/or short interresponse times.

In contrast, Collier, Hirsch, and Kanarek (1977) found that rats would lever press 5120 times to earn a large reward (a meal) during 24-hr sessions. If, as hinted by these results, magnitude of reward affects the point of strain, then pigeons in the present experiment, each of which completed a fixed ratio to earn its entire daily intake of food, should sustain key pecking on much higher fixed ratios than pigeons in previous experiments. Thus, the first experiment attempted to characterize the molar functional relations between magnitude of reward and key pecking and eating by pigeons in a closed economy. We also explored the possibility that ratio strain could be characterized by the economic concept of “price” which related cost (number of key pecks) to benefit (number of grams eaten).

Method

Subjects. Three female White Carneaux pigeons about 6 years old were housed individually, with water and grit freely available in the home cage.

Apparatus. One Lehig Valley Electronics three-key pigeon chamber was positioned inside a sound attenuating enclosure. The feeder was modified to allow measurement and control of time spent eating (Fernie, 1971). Availability of grain was signaled by illumination of the hopper aperture. The pigeon raised the food tray by blocking light to a photocell mounted inside the aperture. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure. Each pigeon was trained on two different experimental procedures. During 3-hr paired baseline sessions, each pigeon received simultaneous access to food and to the response key. The hopper aperture was continuously illuminated and the food tray was raised whenever the pigeon triggered the photocell circuit. Pecks to the right-hand response key, illuminated with a green light, were measured, but had no programmed consequences. During 3-hr contingency sessions, the key peck on the illuminated right-hand response key, which completed the fixed ratio simultaneously darkened the response key and illuminated the hopper aperture for the remainder of the session. Neither key pecks to the darkened key nor key pecks toward the unsuccessful completion of the fixed ratio were carried over from one session to another. After each session, the experimenter collected spillage, measured the weight of grain eaten by the pigeon, emptied and refilled the hopper with fresh grain.

Sessions always terminated automatically after 3 hr in all three experiments. Key peck access time refers to the time from the beginning of the session to the completion of the ratio requirement, and food access time refers to the time that remained in the session for feeding. In all three experiments rate of key pecking equals number of key pecks divided by key peck access time. Even though we appeared to employ a small number of training sessions relative to standard practice, both Collier and Rovee-Collier (1981) and Logan (1960, 1964) have indicated that an animal’s responding rapidly stabilizes when trained on the “free behavior” procedure or closed economy.

Pigeon 1254 received one 3-hr experimental session on days when it weighed about 75% (±10 g) of its free feeding weight. One to five days intervened between successive sessions to allow the pigeon to return to its 75% body weight. Nine baseline sessions preceded contingency training on an ascending series of 16 ratios that began at FR-10 and ended at FR-5100. From FR-100 through FR-1100 the increment was 200 key pecks; from FR-1100 through FR-5100 the increment was 400 key pecks. After five training sessions on one ratio, the requirement was raised to the next higher level for five sessions.

Pigeons 1717 and 1447 received one 3-hr session each day. Body weight was determined by food intake during the previous session. Ten baseline sessions preceded contingency training. Pigeon 1717 key pecked on an ascending series of 25 ratios beginning at FR-10, -200, and then incrementing by 200 key pecks until ending at FR-4800. Pigeon 1447 key pecked on 20 ratios beginning at FR-10, -25, -50, -100, -200, and then incrementing by 200 key pecks until ending at FR-3200. Each pigeon was trained on each ratio for seven sessions. The study ended when a pigeon failed to complete a particular ratio for seven successive sessions. One reason for the difference in the initial sequence of ratios is that Pigeon 1447 was trained on this procedure first and these small increments seemed unnecessary when training Pigeon 1717 on this procedure.

Results

Two of the three pigeons either completed the fixed ratio and ate a meal or did not key peck at all during contingency sessions. Thus, we distinguished between means per session (e.g., mean rate of key pecking per session was averaged over all sessions on a particular ratio requirement) and means per meal (e.g., mean rate of key pecking per meal was averaged only over sessions in which the pigeon completed the ratio and ate).
**Key pecking.** Pigeon 1254 completed all ratios except FR-4700 and FR-5100. The pigeon completed FR-4700 during its first four sessions of training, but not during its fifth session. The bird started, but never completed, the FR-5100 requirement during its first three sessions of training and failed to key peck at all during the last two sessions. Figure 1 shows that mean rate of key pecking per session initially increased through FR-300 and FR-500 and then decreased.

![Graph showing rate of key pecking per session](image)

*Figure 1. Mean rate of key pecking per session by Pigeon 1254 as a function of fixed-ratio requirement in 3-hr sessions.*

Figure 2 displays the results for Pigeon 1717. The mean rate of key pecking per session remained relatively constant as the ratio increased except for the initial peak at FR-400, whereas the mean rate of key pecking per meal generally increased as the ratio increased except for the initial peak at FR-400. The mean number of key pecks per session initially increased until FR-2000; thereafter, it remained relatively stable until FR-4800. Figure 3 shows similar results for Pigeon 1447 which did not produce the initial peak in rate of key pecking and stopped key pecking at a much lower ratio.

**Eating.** Pigeon 1254 ate a mean of 64.0 g per session during baseline training at its 75% body weight (450 g). During contingency training the mean number of grams eaten per session ranged from 70.8 to 89.6 g except at FR-4700 at which it decreased to 36.8 g per session or to 46.0 g per meal. The mean food access time per meal at FR-4700 was 45 min.

The dashed lines in Figure 4 indicate that Pigeon 1717 ate a mean of 28.0 g per session and weighed about 546 g during baseline training. Figure 4 also shows that the mean number of grams eaten per session decreased whereas the mean number of grams per meal increased as a function of ratio size, number of meals per week decreased from seven meals per week at FR-10 through FR-400 to approximately one meal per week at FR-4000 through FR-4600, and the mean body weight per session decreased steadily as ratio size increased. The bird obtained its last meal at approximately 86% of its free-feeding weight, and the mean food access time per meal was 72 min. When the experiment terminated at FR-4800 the bird's body weight was approximately 76% of its baseline level.

Pigeon No. 1447 ate a mean of 36.6 per session and weighed about 542 g during baseline training. Figure 5 shows results similar to those for Pigeon 1717 except that Pigeon 1447 maintained its body weight longer and then lost body weight more rapidly. The bird obtained its last meal at approximately 86% of its free-feeding weight, and the mean food access time per meal was 116 min. Pigeon No. 1447 weighed approximately 75% of its baseline level at FR-3200 when the experiment terminated.

**Price.** Number of key pecks rose steadily as price increased until Pigeon 1254 key pecked approximately 60 times for each gram eaten at FR-4300. Number of grams eaten remained relatively stable despite price increases. Both number of key pecks and number of grams eaten decreased when price increased to 120 key pecks per gram eaten at FR-4700. For Pigeons 1717 and 1447 number of key pecks increased, and number of grams eaten decreased steadily until the price approximated 50-90 key pecks per gram eaten at FR-4600 and FR-3000, respectively.
Discussion

These results illustrate that a "free behavior" procedure or closed economy allows pigeons to adapt in various ways to schedules challenging their intake of food. These results also raise questions about traditional explanations and the most sensitive and appropriate measures of ratio strain.

In keeping with the results obtained in experiments using standard practices, two of the three pigeons produced a bitonic functional relation between rate of key pecking and the size of the fixed-ratio requirement. All three pigeons key pecked on much higher ratio requirements than did pigeons in previous experiments (Ferster & Skinner, 1957; Hogan & Roper, 1978). The finding that a large reward increased the point of ratio strain raises two questions. The first concerns the adequacy of an explanation that focuses on the work requirement, especially in light of an alternative hypothesis that ratio strain will be directly related to magnitude of reward (see also Hodos & Kalman, 1963). The second question is whether the most sensitive and appropriate measure of ratio strain is the point at which there was: (a) a maximum number of key pecks or rate of key pecking, (b) complete cessation of key pecking, (c) a maximum price paid, or

(d) a disruption of key pecking, in which the duration of the post-reinforcement pause increases substantially—the way ratio strain is typically characterized by experimenters using standard practices.

The present experiment also demonstrated a functional relation between the frequency and size of a meal and the size of the fixed ratio. Each pigeon key pecked more frequently to obtain a meal and increased meal size as ratio size increased. Pigeon 1254 produced a relatively small increase in meal size, whereas Pigeons 1717 and 1447 at least doubled their meal size as the number of sessions with the meal decreased from seven to one per week. The small increase in meal
altered at much lower ratios when retrained on this procedure. Finally, these results raise the question as to whether a more sensitive and appropriate measure of ratio strain might also be: (a) a change in the frequency and size of meals and (b) a change in body weight.

Experiment 2

Ferster and Skinner (1957) reported that pigeons ate approximately .25 grams per 3- to 4-s hopper presentation and that ratio strain occurred when pigeons were required to key peck 50-150 times per hopper presentation (a price ranging from 200-600 key pecks per gram eaten). In contrast, the results of Experiment 1 indicated that ratio strain occurred at a higher requirement but a lower price. These differences suggest that there is a functional relation between ratio strain and extreme magnitudes of reward. The primary goal for the second experiment was to examine key pecking and eating by a pigeon working on a simple fixed-ratio schedule in a closed economy. The secondary goal was to determine whether ratio strain was functionally related to intermediate magnitudes of reward. One question was whether a single function would describe the relation between key pecking and price across a variety of schedule-reward magnitude combinations.

Method

Subjects. Pigeon 6707 was maintained and tested under the same deprivation conditions as Pigeon 1254.

Apparatus. The chamber was the one used in Experiment 1.

Procedure. The general procedure was the same as in Experiment 1. One major difference was that the pigeon earned only limited access to food (a bite) each time it completed the fixed ratio during the 3-hr session. After the pigeon consumed the reward (by eating for the number of seconds allotted by a timer that operated only when the photocell circuit was triggered) the hopper light was terminated, and the response key again was illuminated. A second major difference was that the ratios were preselected in an attempt to determine the point of ratio strain rather than increased gradually for each reward magnitude.

Pigeon 6707 was given 13 baseline sessions consisting of eight precontingency and five postcontingency sessions. The pigeon performed on 18 different schedule-reward magnitude combinations formed by combining six fixed ratios (10, 25, 50, 100, 200 and 300 key pecks) with three reward magnitudes (3, 9, and 15 s of eating). The bird proceeded through an ascending series of fixed ratios with reward magnitude held constant at 3, 9, and 15 s of eating, successively. Thus, the pigeon's first contingency session required completion of a FR-10 requirement for 3 s of eating and the final contingency session required completion of a FR-300 requirement for 15 s of eating. This bird previously had key pecked on a variety of schedule-reward magnitude combinations and its responding rapidly stabilized within 4 to 6 sessions (see also Collier & Rovee-Collier, 1981; Logan, 1960, 1964, for similar results). The scores from the final three sessions for each combination of schedule and reward magnitude were averaged.

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Figure 5. Mean number of grams eaten (upper panel), mean number of meals per week (center panel), and mean body weight (lower panel) as a function of fixed-ratio requirement in 3-hr sessions by Pigeon 1447. The filled circles represent means per session whereas the open circles represent means per meal. Dashed lines indicate paired baseline levels.
**Results**

Figure 6 presents mean number of key pecks and mean number of grams eaten as a function of fixed-ratio requirement and magnitude of reward. Figure 7 replots both measures as a function of price.

![Graph of key pecks and grams eaten](image)

**Figure 6.** Mean number of key pecks (upper panel) and mean number of grams eaten (lower panel) in 3-hr sessions by Pigeon 6707. Dashed lines indicate the paired baseline levels of key pecking and eating. Each point represents one of 18 schedule-reward magnitude combinations formed by combining six fixed ratios (10, 25, 50, 100, 200, and 300 key pecks) with three reward magnitudes (3, 9, or 15 s of eating); reward magnitudes are designated by circles, squares, and triangles, respectively.

**Key pecking.** The functional relationships describing mean rate of key pecking and mean number of key pecks were identical. For each reward magnitude key pecking initially increased, then decreased, as a function of ratio size. At lower fixed ratios (10, 25, and 50 key pecks) the mean number of key pecks was inversely related to reward magnitude, whereas at higher fixed ratios (200 and 300 key pecks) mean number of key pecks was directly related to reward magnitude; however, at the intermediate fixed ratio (100 key pecks) there was no systematic relationship between key pecking and magnitude of reward.

**Eating.** The mean number of grams eaten was greater in postcontingency baseline sessions (96.8 g) than in precontingency baseline session (77.4 g); the overall mean was 84.8 g. Figure 6 shows that each contingency reduced eating below its baseline. The mean number of grams eaten varied directly with reward magnitude and inversely with ratio size.

**Price.** Figure 7 shows that number of key pecks increased until it peaked at approximately 150-195 key pecks per gram eaten; thereafter, number of key pecks decreased with further increases in price. It is unclear whether there is one general function or whether there is a separate function for each magnitude.
pigeons key pecking on FR-1 schedules also worked at a constant rate, and then abruptly quit responding (see also Sidman & Stebbins, 1954, for similar results with rats, cats, and monkeys). However, the failure to key peck more frequently on all schedule-reward magnitude combinations cannot be attributed to satiation because the bird always fell short of its baseline level of eating.

These results show that ratio strain is directly related to magnitude of reward across a range of intermediate values. For Pigeon 6707, number of key pecks initially increased as the price increased and then decreased with further increases in price. Even though it is unclear whether there is one general function, or whether a separate function exists for each magnitude of reward, the inflection point suggests that if price exceeds a value of approximately 170 key pecks per gram eaten, the number of key pecks declines and thereby defines a point of "strain". This outcome corroborates the report of Ferster and Skinner (1957) that pigeons showed ratio strain when required to key peck 50-150 times per hopper presentation or a price of 200-600 key pecks per gram eaten. Ratio strain thus appeared to occur at about the same price no matter what the size of the ratio requirement or the magnitude of reward. However, in comparison to Experiment 1, ratio strain occurred at a higher price and the pigeon continued to key peck rather than ceasing altogether after the point of strain.

**Experiment 3**

Ratio schedules are unique because the experimenter specifies the exact relation between number of key pecks and magnitude of reward. In contrast, the subject trained on interval schedules determines the relation between number of key pecks and magnitude of reward. Traditionally, responding on simple variable-interval schedules has been insensitive to manipulations of magnitude of reward (Catania, 1963; Jenkins & Clayton, 1949; Keesey & Kline, 1961). These experiments typically employed deprived pigeons key pecking on relatively long variable-interval schedules for a limited number of small rewards per session. The primary goal of the third experiment was to examine key pecking and eating by pigeons working on a simple variable-interval schedule in a closed economy. The secondary goal was to determine: (a) whether "strain" would occur when pigeons key peck on variable-interval schedules, (b) whether "strain" was influenced by magnitude of reward, and (c) whether the point of "strain" might be determined by a single cost function.

**Method**

**Subjects.** Three female White Carneaux pigeons, about 6 years old, were maintained and tested under the same motivational conditions as Pigeons 1254 and 6707.

**Apparatus.** A second Lehigh Valley Electronics three-key pigeon chamber was also modified as in Experiment 1.

**Procedure.** The general procedures were the same as those employed in Experiment 2. Each pigeon received 3-hr paired baseline and variable-interval contingency sessions. Estimates of the baselines of grams eaten and key pecks were made by averaging the scores from either 13, 15, or 17 postcontingency baseline sessions for Pigeons 7239, 8856, and 7535, respectively. Each pigeon
performed on six different schedule-reward magnitude combinations formed by combining two variable intervals (30 or 240 s) with three reward magnitudes (3, 9, or 15 s of eating). In each of two replications the pigeons traversed an ascending series of reward magnitudes with the schedule held constant at either 30 or 240 s. The order of schedule presentation was balanced across subjects. Training on a particular schedule-reward magnitude combination was terminated when the number of key pecks stabilized. Each data point represents an average of six scores obtained from the final three sessions of the first replication and the final three sessions of the second replication for each schedule-reward magnitude combination. The one exception is for number of grams eaten during training on VI 30-s schedule. This measure equals the average of three sessions of the second replication only because we did not measure number of grams eaten until after completing the ascending series of the first replication. For the same reason baseline sessions are postcontingency only.

**Results**

Figure 8 presents the asymptotic performance of the three pigeons. Figure 9 replots key pecks and grams eaten as a function of price for each individual pigeon.

Figure 9. Mean number of key pecks (upper row) and mean number of grams eaten (lower row) in 3-hr sessions for Pigeons 7239 (left panels), 8856 (center panels), and 7535 (right panels). Stars indicate the paired baseline levels of key pecking and eating. Each of the 6 points in each panel appears as a function of its price; reward magnitudes are designated by circles, squares, and triangles, respectively.

**Key pecking.** Figure 8 shows that the baseline levels of key pecking were essentially zero. The overall rates of key pecking by Pigeons 7239 and 8856 were high and comparable, and contrasted with the low overall rate of key pecking by Pigeon 7535. Averaged across magnitudes of reward, key pecking was more frequent on the VI 240-s schedule than on the VI 30-s schedule for all three birds. Key pecking on the VI 240-s schedule was not systematically related to magnitude of reward; however, key pecking on the VI 30-s schedule requirement was inversely related to reward magnitude. Averaged across variable-interval schedule, key pecking was inversely related to reward magnitude. All three birds pecked more for 3 s than for 9 s of eating, and two of the three birds key pecked more for 9 s than 15 s of eating; the one inversion occurred for Pigeon 7535 which pecked somewhat more frequently for 15 s than for 9 s of eating. The functional relation was the same for rate of key pecking and number of key pecks.
Eating. Mean number of grams eaten during contingency sessions was substantially less than its baseline level except on a VI 30-s schedule for either 9 s or 15 s of eating in which case all three pigeons almost reached their baseline levels of eating. In addition, Pigeon 8856 obtained less food on the VI 30-s schedule for 15 s of eating than during baseline. Averaged across magnitudes of reward, mean number of grams eaten was greater on the VI 30-s schedule than on the VI 240-s schedule. Averaged across variable-interval schedules, mean number of grams eaten was directly related to magnitude of reward. For all three birds the mean number of grams eaten was greatest for 15 s of eating, intermediate for 9 s of eating, and least for 3 s of eating.

The mean number of times that the pigeon completed both the variable-interval requirement and the allotted amount of eating, N, was relatively constant across reward magnitude for the VI 240-s schedule, but varied inversely with magnitude of reward on the VI 30-s schedule for all three birds.

Price. Figure 9 shows that the mean number of key pecks increased sharply with initial increases in price and then leveled off and remained relatively constant with further increases in price. Unfortunately, there were few data points in the middle price range. The maximum price is somewhat higher (200-300 key pecks per gram eaten) than in Experiment 2. The number of grams eaten decreased as a function of price.

Cumulative record analysis. The available cumulative records indicated that all three pigeons key pecked at a relatively constant rate throughout the entire session on all schedule-reward magnitude combinations. The local rate of responding remained constant even on combinations that entailed responding on the VI 30-s schedule for either 9 s or 15 s of eating, in which distinct periods of key pecking and eating, and periods of pausing were discernible.

Discussion

In seven of nine comparisons key pecking increased as the requirement increased from VI 30-s to VI 240-s. This finding resembled the result of Experiment 2 in which key pecking increased as ratio size increased (see also, Lucas, 1981). The total number of key pecks increased as reward magnitude decreased on the VI 30-s schedules, but not on VI 240-s schedules. Both number of key pecks and N on the VI 240-s schedule were unaffected by magnitude of reward, even though the number of grams eaten increased systematically as a function of reward magnitude. This outcome confirmed Catania’s (1963) report that key pecking on simple variable intervals was insensitive to manipulations of magnitude of reward. Catania’s (1963) standard procedure was analogous to the VI 240-s schedule in the present experiment because the pigeons collected only a fixed number of small rewards per session and also ate less during contingency sessions than during baseline sessions.

In contrast, number of key pecks and N on the VI 30-s schedule requirement were inversely related to magnitude of reward. This outcome also was reported for pigeons key pecking on simple fixed-interval schedules (Lucas, 1981). Moreover, this result resembles the outcome of Experiment 2 and previously cited studies that demonstrate an inverse relation between responding and eating on low fixed ratios.

These results are inconclusive with respect to the questions whether key pecking will be strained on variable-interval schedules, and whether there is a single price that defines the point of strain. Visual inspection of Figure 9 revealed a general tendency for the total number of key pecks to increase and then decrease as price increased; however, this peak was not as pronounced as in Experiment 2. It was impossible to determine whether the relatively constant number of key pecks represented either a true asymptote or samples from the ascending and descending wings of a curvilinear function as shown in Figure 7. Because the pigeon determined its own price, the absence of middle prices is interesting even though we have no explanation for it.

General Discussion

Pigeons trained on fixed-ratio and variable-interval schedules in a closed economy key pecked more frequently in response to initial increases in the requirement or to decreases in magnitude of reward. However, key pecking decreased, or ceased altogether, with further increases in schedule requirement.

Our results suggest that pigeons in a closed economy adapt in complex ways to the constraints of a schedule and that ratio strain is not a unitary phenomenon. Traditional measures of ratio strain such as (a) the maximum number of key pecks or maximum rate of key pecking on a given schedule, (b) the cessation of key pecking, (c) the return to the operant level of key pecking, and (d) the disruption in the pattern of key pecking, in which the duration of pauses increase, do not necessarily occur at the same point. Several novel measures of ratio strain such as (a) the maximum price paid, (b) changes in the size and frequency of individual meals, and (c) changes in overall body weight appeared to be more sensitive and potentially appropriate indices of ratio strain.

Our results have implications for Skinner’s (1938, 1953) explanations of ratio strain. The hypothesis attributing ratio strain to fatigue or to a physiological limit on total number of key pecks implies that the only determinant of ratio strain is the size of the ratio requirement. Even though the results of the first and second experiments demonstrate that the point of strain depends on the magnitude of reward (see also Ferster & Skinner, 1957; Hodos & Kalman, 1963), the finding that Pigeon 6707 key pecked more frequently on schedule-reward magnitude combinations entailing lower fixed ratios or larger rewards than those which produced ratio strain indicates an effect of the work requirement per se.

The extinction hypothesis was disconfirmed. First, once the pigeon in Experiment 2 began to key peck, it continued at a high and steady rate until the ratio was completed. The decrease in the overall number of key pecks was due to increased pauses during the session rather than to a progressive deterioration in key pecking. Second, the pigeons in Experiment 1 either began and completed the fixed ratio or did not key peck at all in a particular session.

One alternative hypothesis, not eliminated by our results, is that ratio strain may be related to a regulatory phenomenon in which the subject defends its access to a commodity (Collier et al., 1977; Timberlake, 1980) and also balances the benefit of access against the cost of procurement (Krebs, 1978). Thus, an animal trained on a ratio schedule initially responds to increase access to the restricted commodity until the point at which the costs of its behavior exceed
the benefits obtained. This hypothesis implies that a single function would relate price to ratio strain. Even though our results were ambiguous with respect to such a simple analysis, this idea requires further examination and extension to explain why key pecking on ratios and intervals differs with respect to the sharpness of the point of ratio strain.

An economic analysis provides a second alternative hypothesis for our results. The economic explanation for the declining portion of the bitonic performance functions obtained in our experiments is that the pigeon substitutes leisure for the commodity of food as the price of food increases. Because such a substitution in Experiment I seems strange for an animal threatened with starvation, it would seem that the concept of leisure must be refined before this hypothesis is plausible. Second, the finding that number of grams eaten decreased as a function of price is a simple demonstration of the demand curve.

Finally, there are two further alternative hypotheses consistent with our results: the minimum distance hypothesis (Staddon, 1979) and the learned performance equilibrium hypothesis (Timberlake, 1980). Staddon (1979) showed that maintaining a minimum euclidian distance between the baseline and performance under schedule constraint will result in an initial increase in instrumental responding as the ratio increases followed by a decrease in responding as ratio size increases further. Timberlake (1980) proposed that asymptotic responding represents a trade-off between the value of the excess in the instrumental response over its baseline and the value of the deficit in the contingent response below its baseline. Given a scale in which the value of a unit of excess and deficit varies directly with the distance from the baseline, the subject should decrease total instrumental responding as the (negative) value of the excess exceeds the value of the reduced deficit with fewer repetitions of the instrumental requirement (see also, Hanson & Timberlake, 1983). Even though these two explanations are applied to the present data only qualitatively, both predict that there should be a single function which describes responding under different schedules. A closer examination of these explanations will require more careful quantitative and empirical analyses of the price function relating cost to benefits.

References


