Fixed-Ratio Schedule Performance of Possum (*Trichosurus vulpecula*)

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The first experiment measured possums' food preferences in order to select a consequence that could be used to maintain their behaviour. Four brushtail possums (*Trichosurus vulpecula*) were presented with nine different foods, randomly paired. Their selections were used as indicators of preference. Carob was selected most often on average and this was chosen for use as the consequence. In the second experiment the possums learned to operate a key for 3-s access to carob chips, initially under a fixed-ratio 1 schedule, then under a fixed ratio 5. The schedule was then increased after every five sessions until a subject had received no reinforcer for two consecutive sessions. The fixed-ratio cycle was then repeated. Overall response rates initially increased with fixed-ratio size and then there was either no further trend or a continuing increase as the fixed ratio increased further. Average post-reinforcement pauses were generally short across small fixed ratios and increased at larger fixed ratios. Total session running response rate changed inconsistently across subjects and cycles. In contrast, analysis of the cumulative records showed response runs remained reasonably constant in rate as fixed ratio increased. These different results are a product of the within-ratio pausing which is included in the total session response rates. The results show that possum behaviour can be studied under laboratory conditions and that the behaviour maintained under fixed-ratio schedules by carob was generally consistent with that found for other species.

During the 1830's the brushtail possum (*Trichosurus vulpecula)* was introduced into New Zealand for its fur. It soon became apparent that their detrimental effect was considerable and they have continued to affect New Zealand's fauna and flora (Rose, Pekelharing, Platt & Woolmore, 1993) with an estimated 70 million possums browsing on these. Possums are also an important vector of Bovine Tuberculosis in cattle and deer herds (Morgan, 1990).

There is research on brushtail possums in their natural habitat (e.g., Hickling & Pekelharing, 1989; Rose et al., 1993; Cowan, 1990; Cowan, Chilvers, Efford & Mcelrea, 1997) but little is known of their learning abilities. There are two published studies on brushtail possums' learning under experimental conditions. Pollard and Lysons (1967) investigated the behaviour of six 9-18 month old brushtail possums on pairs of maze problems. One problem in each pair could be solved visually but the other could be solved only by trial and error. Pollard and Lysons (1967) found a wide range of performances and concluded that brushtail possums were less efficient than cats or rats on both visual and non-visual closed-field maze problems.

Kirkby and Williams (1979) initially trained eight brushtail possums to displace a stimulus block with their nose for access to a musk water solution. Then four were placed on left *vs* right and four were placed on light *vs* dark successive discrimination reversal tasks. All the position-discrimination group learned the original discrimination and 19 reversals. Errors and trials-to-criterion declined significantly over successive reversals, with some possums exhibiting one trial learning. In contrast, no possum achieved even the first reversal on the brightness problem.

These two studies provide some information on brushtail possums' learning abilities. They show that their behaviour can be studied under experimental conditions and that they can acquire specified behavioural responses. There are no studies of brushtail possum behaviour under simple schedules of reinforcement. The purpose of the present study was to examine this. In order to do so, an appropriate consequence had to be identified.

Experiment 1

Under a schedule of reinforcement, a specified (normally arbitrary) response results in a rewarding consequence, termed a reinforcer, according to some pre-specified rule. Items an organism will consistently choose often make appropriate reinforcers. In selecting reinforcers for experimental research, ease of delivery, availability, perishability, and affordability all need to be considered. Biologically significant events, such as food and water, often meet these requirements and preferred foods are frequently useful reinforcers.

Brushtail possums have been described as opportunistic herbivores (Cowan, 1990) and solitary fossick-feeders (New Zealand Forest Service, 1982). Feral possums feed mainly on leaves, but also eat buds, flowers, fruits, ferns, bark, fungi and invertebrates. They will consume grain and vegetable crops, horticultural produce and flowers and will sometimes eat small birds and mice. In captivity, possums consume a wide variety of foods including lucerne, clover, dock, swede, silverbeet, grain, maize, apples, dried peas, cabbage, carrots and bread, rabbit pellets and meat (Cowan, 1990).

While brushtail possums' dietary habits are well described there is, however, limited information on their food preferences. Morgan (1990) assessed their preferences for 39 different flavours, such as orange, raspberry and carrot, all added to barley. Only orange-flavoured barley was eaten more than ordinary barley. Nineteen of the flavours were eaten less than ordinary barley and, for 19, the amount consumed was the same as for ordinary barley. It is not clear if these results, based on flavoured barley, would apply to the feeds themselves.

The lack of research into brushtail possums' food preferences meant that further data were needed to help identify a reliable reinforcer. This experiment, therefore, assessed the food preferences of possums by presenting pairs of foods. The foods were selected from suggestions made by possum trappers and handlers and for their availability and ease of presentation.

Method

Subjects

The subjects were four experimentally naive mature male brushtail possums (*Trichosurus vulpecula*), numbered S1 to S4, captured as backriders or pouch young during October 1992. They were housed in a group cage until August, 1994, and were then adapted to individual cages. They were fed commercial possum pellets ad libitum, one apple a day, and, occasionally, dock leaves. These were provided after the daily experimental session. Water was available at all times. Each subject was weighed once a week.

Apparatus

The four individual rectangular wire cages (65 cm x 50 cm x 70 cm) each had a metal nest box (50 cm x 25 cm) attached to the top of one side. Each cage had a mezzanine floor, 28 cm wide, attached 12 cm from the base and a metal door (32 cm x 65 cm) on the left front. The door and the front cage wall had slots through which plastic food containers could be slid. The cages served as the experimental chambers. The housing room was illuminated by a 100-W white light bulb from 9 pm to 9 am, and was in darkness from 9 am to 9 pm.

Procedure

The nine foods used were *Pebbles* (a sugar coated chocolate sweet), hard aniseed sweets, dock leaves, carob chips, lemon rinds, dried pineapple pieces, fresh apple pieces, condensed milk and sultanas. The food samples were presented in similar sized pieces; one Pebble, an equal sized piece of aniseed, a 1 cm diameter piece of dock leaf, six pieces of carob chips, a 1 cm square of lemon rind or dried pineapple, a small piece of apple, two sultanas and a half a teaspoon of condensed milk.

All possible pairwise combinations of the foods were tested with each subject. To arrange this the 72 possible pairings of the foods was repeated four times. This gave 288 pairs, with each food appeared four times as the left-hand member of a pair and four times as the right-hand member of the same pair. The 288 pairs were randomly allocated to nine groups of thirty and one of eighteen. One group was presented in each session over ten sessions. Plastic food containers were used to present the foods, with one food on the left and the other on the right of the same container and with one container for each possum. The first food eaten was recorded. The subjects were so fast at selecting the first food that it was impractical to record latency to first food choice. The container was removed once the first food item had been selected. The daily experimental sessions were run consecutively for each possum, starting at 1 pm.

Results

Figure 1.1 shows the percentage of times each food was selected over any other food. S1 selected carob chips most often (83%), followed by dock leaves (81%). This possum chose lemon infrequently (6%) and never chose condensed milk. S2 chose condensed milk most (73%) then carob chips (70%), and chose lemon (32%) and apple (10%) least often. S3 chose carob chips (75%) and condensed milk (65%) most, and lemon (34%) and apple (12%) least often. S4 chose condensed milk most (73%) followed by pineapple (63%). This subject chose pebbles (41%) and carob (35%) least often.

On average, the foods were selected in the following order; carob chips (66%), dock leaves (62%), sultanas (58%), pineapple (56%), condensed milk (53%), pebbles (51%), aniseed (38%), and apple (28%) or lemon (28%). Carob chips, the most frequently selected food on average, were selected most often by S1 and S3 (83% and 75% respectively) and second by S2 (70%) but were selected the least by S4 (35%). It was, however, still selected some of the time by this possum. Condensed milk was the food most frequently selected by S2 and S4, and second most by S3, but its average was low as it was never selected by S1.

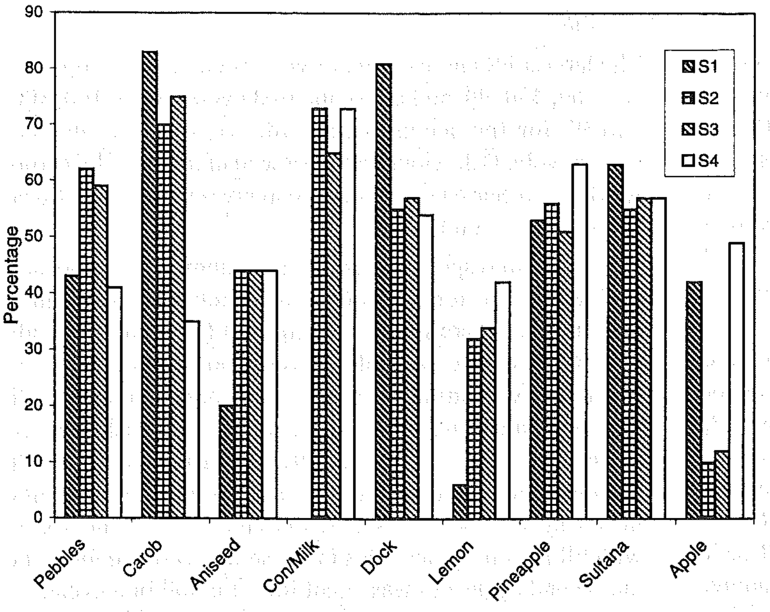


Figure 1.1 The percentage of time each food was selected by each possum.

Discussion

There were clear differences in the preferences of the subjects for each food item, as measured by the percentage of times each food was selected. For each possum there was at least one food that was selected most of the time and one that was selected not at all or very little of the time. The data from S2 and S3 are similar, both chose carob and condensed milk most and lemon and apple least. S4 showed the least variability in food choice but still showed a preference for some foods over others. Sweet foods were generally preferred. Lemon was selected least, on average. The unexpectedly low selection of apple may have been influenced by the apple provided daily. Carob was generally preferred over the other foods and this suggested that it could be used as an effective reinforcer.

Experiment 2

One of the simplest schedules of reinforcement is a fixed-ratio (FR) schedule. This schedule delivers a reinforcer after a set number of responses. The data are analysed by summing across the whole session. The resulting measures include overall response rate (based on the total session time), running response rate (based on the cumulated time from the first to the last response in all ratios in a session), and post-reinforcement pause (PRP) length (based on the cumulated durations of the pauses before the first response after a reinforcer). Cumulative records are also used to allow analysis of fine-grain details of performance (Ferster & Skinner, 1957). These present the cumulative number of responses as a function of session time and also show when reinforcers were delivered. The greater the slope of the record the faster the rate of responding. A linearly increasing record shows the subject was responding at a steady rate. Skinner (1976) pointed out that this method of data presentation was becoming less frequent although it reveals interesting details of performance. These records can now be produced by computer analysis and graphing of electronically recorded data.

The pattern of responding under FR schedules, described as a "stop and go" pattern (Mazur, 1994), has been found to be very similar across species. Cumulative records show there is typically a pause after each reinforcer and then an abrupt change to a rapid constant rate of responding which continues until the next reinforcer (Ferster & Skinner, 1957). The length of the PRP typically increases as the FR increases (Felton & Lyon, 1966; Ferster & Skinner, 1957; Mazur, 1983; Powell, 1968). Although typically running response rates are high and remain constant with changes in FR size, some studies have reported that they decrease with increasing FR (e.g., Foster, Blackman & Temple, 1997).

Cone and Cone (1970) studied the behaviour of two virginia opossum (*Didelphis virginiana)* under FR schedules. They used a 23-hr water deprivation regime and so could use water as the reinforcer. The opossums learned to press a lever with their snouts but changed to using their paws within a few sessions. When they were responding consistently on an FR 10, the ratio was increased gradually to FR 250. PRPs were noted on FRs higher than 100. These pauses increased in length as the FR increased further. Cone and Cone reported that once the opossums had begun a ratio they responded without pausing. Thus, these opossums responded similarly to other species under FR schedules.

There are no studies of brushtail possums' behaviour under FR schedules. This next experiment examined this using carob chips as the reinforcer.

Method

Subjects

The subjects were those used in Experiment 1.

Apparatus

A response panel (31 cm x 66 cm) could be attached to the front of each of the cages used in Experiment 1 in the space provided by the open cage door. Half-way up this panel was the response key. This was a circular (5-cm) perspex disk with a perspex rectangle (3.5 cm x 2 cm) glued to it. They key was situated in a rectangular black backplate (14 cm x 14 cm) and was operational when lit from behind by a 1-W green light bulb. When the key was pressed the keylight extinguished briefly. If a reinforcer was due the keylight remained out while the hopper holding the carob was raised for 3 s. The hopper access hole (3 cm x 2 cm) was situated below the key. The possums could reach the food with their mouths while the hopper was raised, but the hole was small enough to prevent this when the hopper was lowered. All experimental events were controlled and recorded by a remotely situated computer using the Med-PC programming system.

Procedure

Each possum was magazine trained and then trained to operate the key with their mouths using the method of successive approximations (Ferster & Skinner, 1957). During training sessions between 30 and 40 reinforcers were delivered by manual operation of the hopper. An FR 1 schedule was then in effect until all possums were operating the key quickly and readily. The FR was then increased to 2 and then 5. S1 and S4 required eight training sessions, S2 one session, and S3 six sessions.

There were then five sessions with FR 1 and five sessions with FR 5. The FR was then increased by a factor of 1.5 after every five sessions (i.e., to FR 8, FR 12, FR 18, etc). The FR was increased until a subject did not receive a reinforcer for two consecutive sessions. This finished the first cycle for that subject. Following this either FR 1, if there had been no responses for two sessions, or FR 5, if there had been responses, was used to reestablish responding. The FR was then increased through a second cycle, starting at FR 1. The daily 15-min sessions took place consecutively for each possum, starting around 1 pm. The same response panel was used for all possums. The start of a session was signaled by the onset of the green keylight. All data were recorded by the computer.

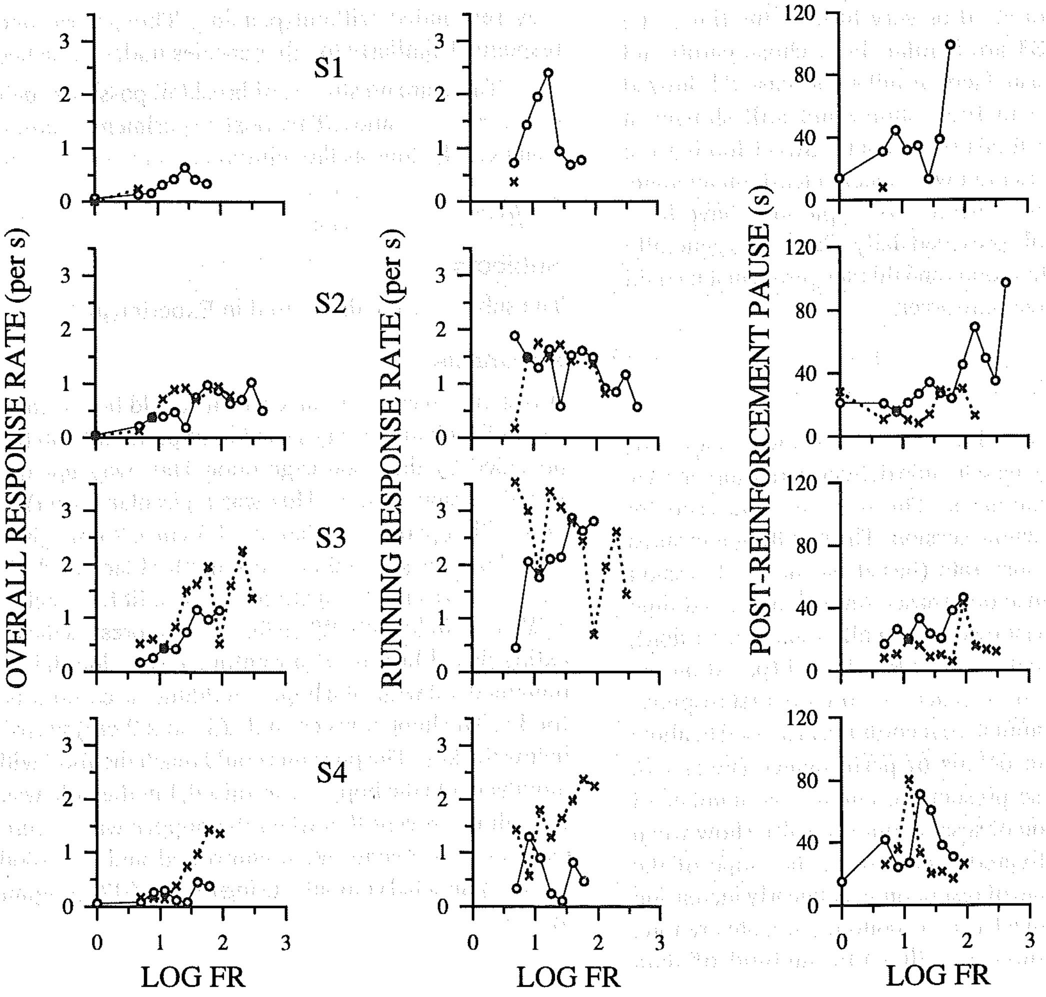
Results

The largest FRs under which five sessions were completed were 60, 450, 90, and 60 for the first cycle, and 5, 140, 300 and 90 for the second cycle, for S1, S2, S3, and S4, respectively. Behaviour was least well maintained by carob for S1, who ceased responding in many sessions and also at FR 8 in the second cycle.

Overall response rates (the total number of responses divided by the total session time, excluding magazine-operation time) are shown in Figure 2.1 (left panel). Not all the FR 1 data were available. These response rates increased as the FR was initially increased in both cycles for all possums. In the first cycle S1's response rate peaked at FR 27 then decreased. After initially increasing, S2's overall response rates remained fairly constant across the larger FRs in both cycles. Overall response rates for S3 and S4 increased with FR in both cycles. This increase was variable for S3 in the second cycle and was small for S4 in the first cycle.

Running response rates (the total number of responses divided by the session time minus the PRP time and magazine-operation time) are shown in Figure 2.1 (middle panel). These rates cannot be calculated for FR 1. Running response rates initially increased as FR increased for S1, S3, and S4 during the first cycle and for S2 in the second

Figure 2.1 The overall response rate, running response rate, and average post-reinforcement pause plotted as a function of the logarithm of FR size, for both the first (circles) and second (crosses) FR cycles, for all subjects.



cycle. They decreased for S1, S2 and S4 as the FR increased further. In contrast, for S3, they generally continued to increase over the first cycle of FRs, as did those of S4 in the second cycle. For S2 in the first cycle and S3 in the second cycle running response rates generally decreased across the FRs, although the decrease was variable for S3.

The average PRP durations (cumulated PRP time divided by the number of reinforcers obtained in that session) are shown in Figure 2.1 (right panel). They remained small and constant as FR increased for S1, S2, and S3 during both cycles, until quite large FRs were reached. Then, for S1 and S2 in the first cycle, they increased as the FR increased further. In both cycles S4's PRP data increased then decreased with FR increases.

Figures 2.2 to 2.5 show a representative selection of cumulative records for FRs greater than 1. Tick marks indicate reinforcer delivery and horizontal lines indicate pausing. On the smaller FRs the subjects had short PRPs and high and steady response rates in the response runs. S1 stopped responding in some sessions. Response runs for S4 were rapid but this subject had longer and more variable PRPs than the others. Response runs increased in rate for S2 after the two smallest FRs, but for the other subjects they remained at around the same rate across all FR values. PRP duration initially remained short, but increased at around FR 40 for all subjects. Although response rates continued to be high when a subject was responding as FR increased, within-ratio pausing, termed ratio strain (Ferster & Skinner, 1957), started to occur.

Throughout the experiment three subjects operated the key with their mouths. Observation showed that response topography changed for a while for S2 in the second cycle when he operated the key with his paw on FRs below 18. Sometimes possums spent time marking the response panel with their own scent when it was first attached for a session.

Figure 2.2 Representative samples of the cumulative records for S1.

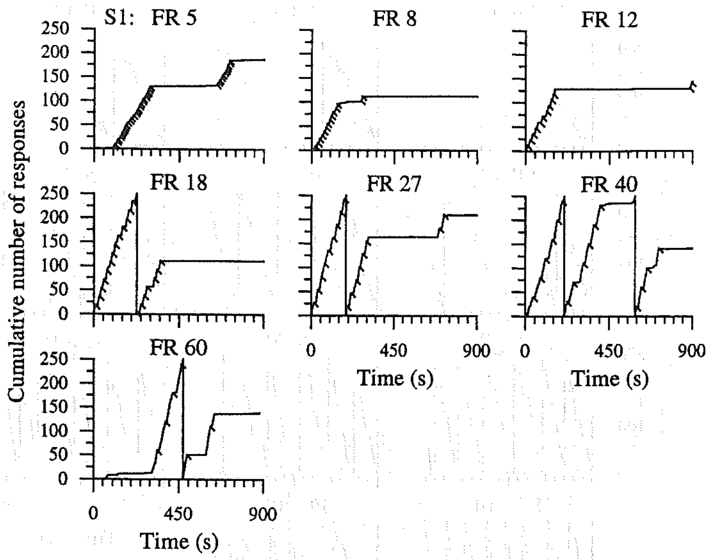
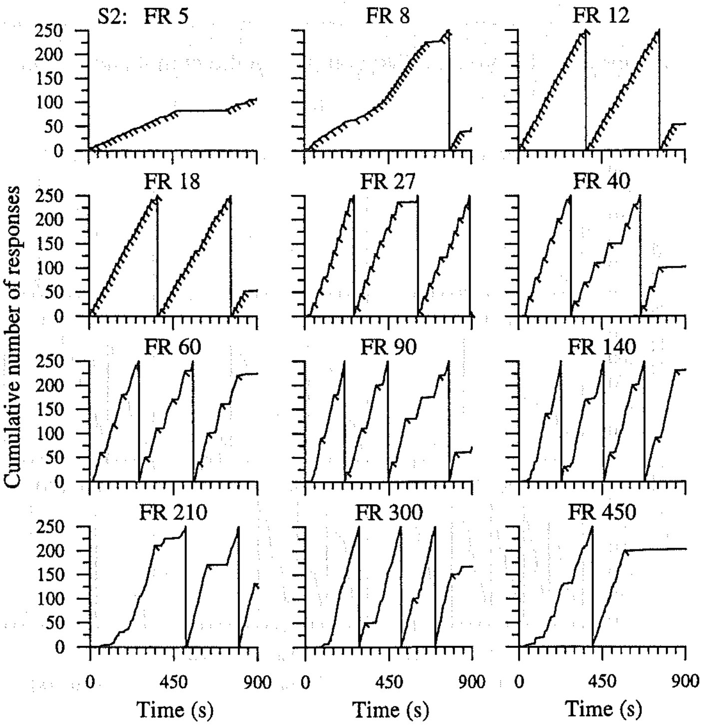


Figure 2.3 Representative samples of the cumulative records for S2.



Discussion

This experiment examined the performance of possums under FR schedules both within and across schedules. Overall response rates showed two distinct patterns. In one they increased as the FR increased over the whole range studied. This finding is similar to the ascending portion of the bitonic overall response rate functions reported for rats by Barofsky and Hurwitz (1968) and Mazur (1983). If the FR had been increased further in longer sessions then it is possible that overall response rates would have eventually decreased, giving bitonic functions. Although Hursh (1980, 1984) suggested bitonic functions are typical for FR schedules, both monotonic decreases (Powell, 1968) and initial increases that stabilise (Crossman, Bonem & Phelps, 1987) have been reported. This latter pattern is similar to the second pattern found here, with overall response rates initially increasing over small FRs (1-27) and then not trending further with further FR increases. It should be noted that whether or not reinforcer time is included or excluded from the calculation of overall response rates alters the shape of the overall response rate function. Blackman (1990) showed that excluding reinforcer time, as was done here, makes the overall response rate functions flatter and less bitonic and, thus, more like the flatter of the functions in the present study. She suggested that the different time bases used

Figure 2.4 Representative samples of the cumulative records for S3.

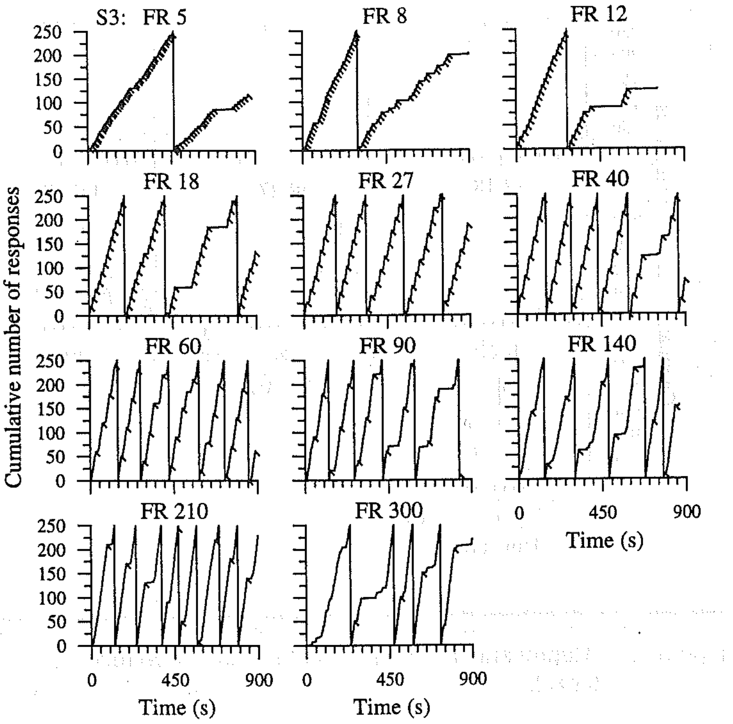
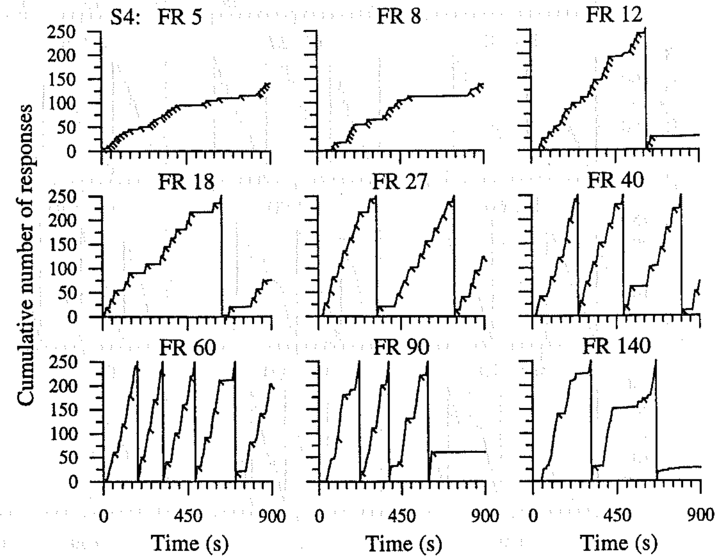


Figure 2.5 Representative samples of the cumulative records for S4.



in different studies may account for some of the different results reported for total session data.

Running response rate generally increased and then decreased as FR increased The increases continued, however, across all FRs for two data sets. While the increases followed by decreases are consistent with the total session data from other studies (Blackman, 1990; Crossman et al., 1987; Mazur, 1983), the continuing increases are not.

The gradual increases in PRP length over initial FRs followed by more rapid increases at larger FRs are consistent with the findings from virginia opossum (Cone & Cone, 1970) and from other studies (Felton & Lyon, 1966; Mazur, 1983; Powel, 1968). However, for some subjects here PRPs remained roughly constant or decreased at larger FRs, both findings not reported in the existing literature. At the start of the second cycle some longer PRPs occurred on the smaller FRs. Ferster and Skinner (1957) found a similar effect when they started a second cycle with short FRs after a period of long FRs.

The cumulative records show patterns of responding similar to those described by others. For the smaller FRs, PRPs were very short for three subjects and, once a response run was started, it continued at a steady rate. As FR increased response runs continued at a rapid and constant rate, but within-ratio pausing began to occur as reported by others (e.g., Ferster & Skinner, 1957). The slopes of the lines indicating response runs in the cumulative records (Figures 2.2-2.5) are similar for most FRs even when the running response rates (Figure 2.1) appear to decrease. Taking the within-ratio pause time out of the calculation of total session running response rates would lessen the decreases in these rates at the larger FRs. These data, therefore, support Felton and Lyon's (1966) argument that lower running response rates sometimes reported for larger FRs are the result of this within-ratio pausing.

An arbitrary response (biting a key) was selected for this experiment. The selection was based both on consideration of the design of the response panel and on the observation that possums will often respond to a novel object by biting it. However, the change in response topography for S2 and for Cone and Cone's (1970) opossums, from using their mouths to using their paws to operate the key, suggests that a key designed to be operated with a paw may work just as well or even better than the present manipulandum. It also appears the possums used their scent gland to mark the response panel each session. Future work could reduce this by providing each possum with its own panel.

Conclusion

In the first experiment, the food preferences of four brushtail possums were studied. A reinforcer was identified and used successfully in the next experiment to study the behaviour of these animals on FR schedules under experimental conditions.

Although carob was most frequently selected by S1 (Figure 1.1) in the preference assessment it did not maintain this subject's behaviour as well as it did the behaviour of the other subjects. While presenting the food items in pairs provided a quick determination of the foods that were frequently selected, it did not assess the degree of preference between the foods. It could be that none of the foods was highly preferred by S1.

The second experiment showed how brushtail possums perform on FR schedules. There was a relation between their response patterns and changes in FR size. The cumulative data show response patterns similar to those found for many other species under FR schedules. Overall response rates, running response rates, and post-reinforcement pauses were similar to previous research but there were interesting differences for some of the possums. These data show that it is possible to use operant methods to study possum learning and they add to the very limited information available on the learning abilities of *Trichosurus vulpecula* - New Zealand's common brushtail possum.

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