QUANTIFICATION OF RATS' BEHAVIOR DURING REINFORCEMENT PERIODS

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What is treated as a single unit of reinforcement often involves what could be called a reinforcement period during which two or more acts of ingestion may occur, and each of these may have associated with it a series of responses, some reflexive, some learned, that lead up to ingestion. Food-tray presentation to a pigeon is an example of such a "reinforcement period." In order to quantify this behavior, a continuous-reinforcement schedule was used as the reinforcement period and was chained to a fixed-ratio schedule. Both fixed-ratio size and reinforcement-period duration were manipulated. Rats were used as subjects, food as reinforcement, and a lever press as the operant. Major findings included (a) a rapid decline in response rates during the first 15 to 20 seconds of the reinforcement periods, and (b) a strong positive relationship between these response rates and the size of the fixed ratio. Also revealed was a short scallop not normally found in fixed-ratio response patterns, whose length was a function of fixed-ratio size and reinforcement-period duration. It is suggested that rapidly fluctuating excitatory processes can account for many of these findings and that such processes are functionally significant in terms of behavioral compensation.

Key words: reinforcement, behavioral compensation, feeding, chain schedules, response patterns, lever press, rats

The traditional analysis of operant behavior has always focused on responding between reinforcers. In the most common schedules, either the number of responses or the amount of time between reinforcers is controlled by the experimenter and the effects of these changes on responding between reinforcers are analyzed, often in terms of rates and patterns of responding. Similarly, when the duration or size of the reinforcer has been manipulated, it has always been for the purpose of examining the effects of these manipulations on behavior between reinforcers. However, what is treated as a single unit of reinforcement often involves a period of time during which two or more acts of ingestion may occur. Each of these may in turn have associated with it a series of responses, some reflexive, some learned, that lead up to ingestion. For example, if key pecking by a pigeon is reinforced by presentation

of a food tray for some period of time, the pigeon emits a number of responses during that time in the form of orienting, pecking, and swallowing actions. The present experiment attempts to quantify responding by rats during such a "reinforcement period." The method involves adding an operant response to those responses already associated with an individual consummatory act that occurs during the reinforcement period. This additional response is designed to be recordable both in time and number. Most will recognize this as Skinner's (1932) original logic in the development of his "feedometer."

Specifically, the method employs fixed-ratio continuous-reinforcement (FR-CRF) chain schedules as defined by Ferster and Skinner (1957), where the CRF component is the reinforcement period. When the FR component has been completed, the rat is allowed a fixed period of time during which each lever press is reinforced, much as is each peck by a pigeon at a food tray during reinforcement. In this way the rate and pattern of responding during a reinforcement period can be quantified and the effects of different FR sizes and CRF durations determined.

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METHOD

Subjects

Four Wistar rats approximately 280 days old when shaping began were used. All had previous experience with the same type of reinforcement schedule in an earlier experiment. At the end of one experiment using similar reinforcement schedules, the rats were returned to free-feeding for 74 to 83 days, followed by 13 days of partial food deprivation that brought their weights down to 80% of normal. The rats were maintained at 80% of their free-feeding weights and housed in opaque plastic cages with metal grid lids.

Apparatus

The experimental chamber was a standard operant conditioning box. Its dimensions were approximately 23.5 by 20.0 by 19.0 cm, with two metal sides, two Plexiglas sides, a Plexiglas lid, and a metal grid floor. The operant lever had an .18 N force requirement and was on one of the metal sides. Three centimeters to its left was a pellet tray, connected to an external Gerbrands Model D pellet dispenser, which used 45-mg Noyes precision food pellets. A white discriminative stimulus light was underneath the pellet tray and below the grid floor. Operation and recording of the experiment were handled by standard relay equipment.

The operant conditioning box was housed in a noise-reduction chamber 60 by 64 by 60 cm, constructed of 1.75-cm thick plywood and 5-cm thick styrofoam. A Plexiglas window in the door of the noise-reduction chamber allowed for direct observation of the subjects. The unit was illuminated by a low-intensity red light and fresh air was circulated by an externally mounted fan.

Procedure

The rats were shaped to their assigned schedules of reinforcement over the first 3 to 4 days. Their previous experience with these schedules made shaping an easy task. The FR component of the chain schedules required 5, 15, 30, or 60 lever presses, followed by a CRF period of 5, 10, 20, or 40 sec, during which every lever press was reinforced with a food pellet. During earlier experiments with similar schedules, it was observed that some rats occasionally pressed the lever twice before eating the resulting food pellets. This happened seldom,

with only certain rats, and during no specific portion of the CRF periods. Thus, it was not deemed necessary to employ a complex system to prevent the rats from obtaining a second food pellet before consuming the first. When the CRF time limit was up, the next lever press was the last one to be reinforced and the FR component came into effect again. The purpose of this was to allow for an accurate measurement of the first interresponse time (IRT) occurring in the FR component of the chain. A light stimulus was off during execution of the FR requirement and on while the CRF component was in effect. Each combination of FR response requirement and CRF duration was used for at least two 15-min sessions, with one session per day. Occasionally a schedule was in effect for three to four sessions when a noticeable change in responding occurred.

All four CRF periods were administered under one FR response requirement, after which the FR was changed and all four CRF periods were readministered in a different order. Each rat received treatment combinations in a different order, as determined by two Latin squares: one for FR requirements and one for CRF-period durations. When all treatment combinations were completed, the rats were placed on CRF schedules for three sessions.

RESULTS

The results of Rat 3 are not presented since abnormally long breaks in responding emerged early in the experiment and persisted throughout the remaining sessions. All data presented have been averaged over cycles and sessions. A cycle occurs repeatedly within a session and is defined as running from the start of the FR component to the end of the CRF component of the chain. Since recording instruments gave only session totals for the dependent variables, cycle to cycle variation is not available.

Figure 1 is typical of the cumulative records obtained using FR-CRF chains. Following a CRF period there was a postreinforcement pause (PRP), which was followed by a period of very rapid FR responding. The CRF periods are shown with a down stroke for each unit of reinforcement obtained. Of particular interest here is that responding during the FR component did not always form a clear step pattern. The interval between the end of CRF and the first FR response was usually the long-

Fig. 1. Example of cumulative record produced by Rat 6 on FR 60—CRF 40-sec chain schedule. Areas with downstrokes indicate CRF responding.

est, after which responses occurred progressively faster, creating a short scallop. Maximum rates were usually attained after five to ten FR responses.

Figure 2 shows the mean terminal rates of responding under each FR. The average rate at which the final four FR responses occurred within cycles was calculated as a measure of terminal rate for FR requirements of 15, 30, and 60. It is apparent that on these schedules, differences in terminal rates were negligible as a function of FR size. Terminal rates on FR 5 were calculated as the inverse of the last IRT in the FR component; calculating these rates from the last four responses as with the larger FRs would have made them even slower, because responding under FR 5 accelerated throughout execution of the FR component, never reaching a maximum. Terminal rates on FR 5 were consistently slower than those on larger FR requirements.

Responding within the CRF component is presented in Figures 3 and 4. These are plots of mean response rates calculated for successive 5- and 10-sec blocks of the CRF periods. In Figure 3, data have been collapsed across the

Fig. 2. Mean terminal response rates as a function of FR size, calculated from the last four responses made during FR components of 15, 30, and 60. For FR 5, rates represent the inverse of the mean final inter-response time of the FR component.

CRF-duration variable and CRF response rates are presented with a separate curve for each FR requirement employed. It can be seen that the general trend for all subjects was for CRF response rates to start off high and then decelerate, rapidly at first but more slowly over time until near baseline rates were achieved. The baseline was taken as the mean response rate taken over two sessions in which the schedule of reinforcement was CRF alone, rather than an FR-CRF chain. Figure 3 also shows a remarkably consistent distinction for all subjects between response rates during the first seconds of the CRF periods, as a function of FR size. Quite clearly the larger the FR requirement was, the more rapid these rates were.

Figure 4 is similar to Figure 3 except here the data have been collapsed across the FR variable and a separate curve is plotted for each CRF duration, for each subject and as a group. The purpose here is to show that CRF response rates did not vary either consistently or appreciably as a function of the duration of CRF component of the given chain schedule. This is apparent from the considerable overlap that occurs.

At the start of the FR component, one could observe a period of slow responding composed of the PRP and the time it took to accelerate

Fig. 8. Mean CRF response rates as a function of FR size and elapsed time of CRF period, for individual subjects and as a group. The baseline shown represents mean response rate when a CRF schedule was in effect for an entire session.

to maximum rates, as illustrated by the scallop effect in Figure 1. In order to measure the time it took to accelerate to near maximum rates, the time elapsed from the end of the CRF

component to the completion of the first inter-response time that was less than one sec was used. The results of this measure are presented in Figure 5 for all FR-CRF combinations for

Fig. 4. Mean CRF response rates as a function of CRF duration and elapsed time of CRF period, for individual subjects and as a group. The baseline shown represents mean response rate when a CRF schedule was in effect for an entire session.

each subject and as a group. In general it can be seen that as FR size increased, the scallop got longer. Although variation due to CRF durations of 10, 20, and 40 sec was less than consistent, the scallop was always shorter when CRF was only 5 sec long.

The overall rate of reinforcement was calculated as the mean total food pellets obtained per session over the total session time for each schedule used. Figure 6 shows these results for

each subject and as a group. Also shown for comparison are baselines that were calculated in the same way, but for sessions in which a standard CRF schedule was used. Rat 4 actually maintained an overall reinforcement rate higher than baseline for many of the schedules used, although the basic trend of slower overall reinforcement rates for more difficult schedules also appeared. This trend was most clearly shown for Rat 5. It was also seen for Rat 6,

Fig. 5. Mean duration of FR scallop as a function of CRF duration and FR size, for individual subjects and as a group. Scallop duration was measured as time elapsed from the end of CRF to the first interresponse time less than one sec.

with the exception of higher overall reinforcement rates under FR-15 components as compared to FR-5 components. Obviously, Rat 6 could have maintained baseline rates for FR 5 but did not.

DISCUSSION

This experiment was designed to quantify behavior during reinforcement periods, but one of the most fascinating results was the consistent occurrence of a scalloped response pattern for the FR component of the chain schedule. This effect was apparent in the cumulative record shown in Figure 1, where responding accelerated for a short time following the PRP, rather than emerging immediately at maximum rates as is characteristic of standard FR schedules (Ferster & Skinner, 1957). The duration of the scallop, including the PRP, was illustrated in Figure 5 for the various schedules employed and showed that the greater the FR, the longer the scallop. This result parallels results with FI schedules: the greater the interval, the longer the scallop. A

Fig. 6. Mean reinforcement rate as a function of CRF duration and FR size, for individual subjects and as a group. Rates were calculated as total food pellets over total session time. The baseline shown represents mean reinforcement rate when a CRF schedule was in effect for an entire session.

similar relationship, though not shown, existed when the PRP was removed from this measure.

The scallop was also shorter on average when CRF lasted only 5 sec as compared to 10, 20, or 40 sec. If one extrapolates from this to a standard FR in which there is an implicit CRF component of very short duration, it is not surprising that the scallop disappears completely, creating the well known steplike cumulative record. It would be premature to draw sweeping conclusions from this, but it certainly suggests that the duration of the scallop might be placed on a continuum, only one point of which, the zero point, is revealed by standard FR schedules. Thus, to view the scallop effect as peculiar to FI schedules is a mistake. By manipulating reinforcer duration, the scallop can apparently be produced for FR and perhaps variable ratio and interval schedules as well, though these latter schedules remain to be tested.

When the response rates within the reinforcement period, shown in Figure 3, are con-

sidered, several aspects of behavior during the reinforcement period are revealed. The response rates decline rapidly during the first 15 to 20 sec of the reinforcement period. This may result largely from an inability to maintain the high consumption rates initially displayed. Of greater interest are the consistent differences in these rates as a function of FR size, where the greater the FR, the faster the initial CRF response rates. This was not a type of momentum effect in which the rats were responding more rapidly at the end of the larger FRs. In this case the differences in initial CRF rates would merely have reflected a slowing down from different FR response rates. Figure 5 showed no appreciable difference in response rates at the end of FR 15, 30, or 60, thus ruling out this explanation.

From a functional perspective, this result seems like a case of behavioral compensation (Baldwin, 1968; Baldwin & Ingram, 1968; Hirsch & Collier, 1974a; Hirsch & Collier, 1974b; Hogan & Roper, 1978), where on more difficult schedules the rats increased their CRF response rates so as to maintain a stable average rate of reinforcement. In fact, as Figure 6 clearly demonstrates, the mean session reinforcement rate generally declined both as FR increased and as CRF got shorter. In most cases, the rats did not maintain the overall rate of reinforcement established during entire sessions of CRF. This was not due to a physical inability to compensate more completely. For example, had the rats responded as fast during CRF when the FR requirement was 30 as when it was 60, they might have greatly improved their overall reinforcement rate.

Thus, the rats only partially compensated for schedule differences. This is not an unusual finding when an open economy is used. Subjects were maintained at 80% of their free-feeding weights regardless of how many reinforcers they obtained within the experimental sessions. The demand associated with the nonessential food pellets used as reinforcers would have been considerably less than with a closed economy in which the reinforcers were the only food source (Collier, 1980; Hursh, 1980). That the rats compensated even partially under an open economy is certainly of interest.

Behavioral compensation is a functional explanation. An alternative type of analysis can also be applied to these results—a dynamic,

causal one that considers the short-term fluctuations in excitatory processes controlling the emission of the operant response. Such a mechanism can be seen as having a compensatory function. This approach is best characterized by the structural models of behavior professed by Tinbergen (1951) and Gallistel (1980). It is useful in this case because it overcomes the ceiling effect on response rates observed at the end of the FR components. In the present case, at the present stage, only the simplest of premises are necessary: (1) When reinforcement is obtained, excitation declines towards some baseline level determined by longer-term learning and motivational factors; (2) between reinforcements, excitation increases towards some maximum level determined by longer-term learning and motivational factors; and (3) the greater the excitation, the greater the response rate.

For the present schedules, it follows from Premises 1 and 2 that excitation builds up during FR responding and declines during CRF responding. The greater the FR component of the chain, the greater the buildup of excitation. Given Premise 3, this should have resulted in different response rates under different FR sizes just before CRF. Unfortunately, these rates were at their maximum for all but the FR-5 schedules, as shown in Figure 2, creating a ceiling effect that masked any existing differences in excitation. It is an advantage, however, of the present method that one can observe what happens when, according to Premise 1, there is a decline in excitation during CFR, which slows response rates and removes the ceiling effect. Different levels of excitation as a function of FR size should still have been apparent at this time in the form of different response rates. Indeed, Figure 3 showed a positive relationship between FR size and CRF response rates, as would be expected.

The purpose of this experiment was not to test any specific hypothesis but rather to propose a quantitative method for studying behavior during the reinforcement period and to establish an initial data base from which further experiments may be generated. A reinforcement period can be set up in a number of ways. It can end after a fixed or variable number of reinforcers have been obtained, or it can last for a fixed or variable amount of time, or some combination of these. As such, it should

be recognized that a standard FR schedule could be reinterpreted as one of a number of FR-CRF chain schedules in which the CFR period is defined as lasting for one response. It is a quantitative, not qualitative, difference between this and a CRF period lasting 2 or 200 responses. This interpretation should seem less radical given the example of a pigeon which is presented with a food supply for a fixed period of time as a unit of reinforcement. The number and rate of responses made during that time have been ignored in the past. The CRF period has an advantage over simple presentation of a food supply in that each consummatory act within the CRF period is treated as a unit and remains contingent upon an operant response that is recordable both in time and number. Thus, the same information is available to the experimenter on behavior during the reinforcement period as has been available in the past about behavior occurring between reinforcement periods.

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