FIXED-INTERVAL REINFORCEMENT OF RUNNING IN A WHEEL¹

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The notion of "rate of responding" in the study of operant behavior presupposes a unit of behavior of which instances can be counted. Such operants as pressing a lever (rat), pecking a key (pigeon), or pulling a plunger (man) are fairly complex sequences of events, with an identifiable beginning and end. The rat reaches toward and grasps the lever, depresses it, allows it to rise, and releases it; or if it keeps hold of the lever, the response begins with depressing the lever and ends with permitting it to rise. In either case the rat is in approximately the same position before and after responding. The response is "phasic"; it can be repeated without engaging in other behavior, and instances can be counted. Changes in rate of responding can be studied.

A countable unit is not always easily identified. In reinforcing a rat for "holding down a lever" or for "standing motionless," for example, we may record time spent in a given position; but it is not clear that duration of not-moving corresponds to a rate of emission. A related problem is raised by continuous responding. Is the rate at which a rat runs down a straightaway equivalent to the rate of pressing a lever?

In approaching this problem, we can begin by noting how a continuous response, such as running in a wheel, changes under certain conditions of reinforcement. A previous report (Skinner, 1938 pp. 355-357) described the behavior of rats reinforced with food for running a given distance in a wheel. In the present experiment, running was reinforced on a fixed-interval schedule.

The problem of defining a "unit" must be met at once in deciding how the movement of the wheel is to operate the food magazine. When the magazine is operated upon completion of a given number of turns, running is reinforced on a "ratio" schedule. But how much of a turn, how much action, is to be called "running" on an interval schedule? In the present case, precision switches operated by a cam on the wheel shaft were arranged 180 degrees out of phase. After a reinforcement was set up by the programming circuit, both switches had to close (in succession) to operate the magazine. In one sense, this defines a unit of running, though it is not clear that such a unit is meaningful in describing behavior throughout the interval.

METHOD

Apparatus

A suitable wheel has been described elsewhere (Skinner & Morse, 1957). A low moment of inertia permits the rat to start and stop almost as quickly as when running on a flat surface. The wheel is 13 inches in diameter, and turns in only one direction against an adjustable friction. A food magazine is located alongside the open face of the wheel. When running, the rat faces away from the food magazine. Running is recorded by having the wheel drive a cumulative recorder through a system of pulleys and gear reductions.

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Procedure

Two brown rats, approximately 100 days old at the start of the experiment, were trained to eat food pellets from the magazine, receiving a total of 75 pellets during three sessions. During this time the wheel was locked. Operation of the magazine was accompanied by a relatively loud noise, produced by a buzzer and a bell, which subsequently would provide strong stimulation at reinforcement regardless of noise produced by the rat itself running in the wheel.

In succeeding sessions the wheel was unlocked, and, in the presence of a 6-watt white light, running in the wheel was reinforced on a 5-minute, fixed-interval schedule (FI 5). It was soon found that spontaneous activity—running without reinforcement—was relevant to the results. The following change was made, therefore, and prevailed throughout the experiment. The rat was put in the wheel, the sound-shielding box was closed, and running in the dark was recorded but not reinforced for 30 minutes. The light, serving as a discriminative stimulus for fixed-interval reinforcement, then came on, and running was reinforced on FI 5. After a given number of reinforcements (at first 50, then 40, later 20), the light was turned off, and the rat was allowed to continue running without reinforcement for 30 minutes. For each session, this procedure gives (a) a sample of the unreinforced rate of running prior to the beginning of fixed-interval reinforcement, (b) the fixed-interval performance, and (c) a sample of subsequent unreinforced running. (Since rate of unreinforced running is generally greater in the dark than in the light, any difference due to the use of the light as a discriminative stimulus would favor running without reinforcement. For the first 15 sessions on FI 5, the wheel turned against a friction which was just overcome by a tangential force of 20 grams. In subsequent sessions the friction against which the wheel turned was systematically varied between 25 and 100 grams.

RESULTS AND DISCUSSION

During the first six sessions on FI the rats ran relatively slowly and showed only a slight effect of the fixed-interval reinforcement. Rat 23 developed the fairly uniform interval scallop shown in Fig. 1A; but this soon deteriorated to the performance shown in Fig. 1B, which is similar to the performance of the other rat. It was then discovered that the pellets used for reinforcing the animals had retained traces of an unpalatable solvent used in their preparation. A new supply produced an immediate increase in rate of running for both rats. At the same time the pulley system driving the recorder was changed so that turning the wheel a given distance moved the recording pen twice as far as in Fig. 1. Figure 2 shows the complete performance of Rat 23 on the first day with palatable food (beginning after the delivery of a "free" reinforcement). At the beginning of the session the rat pauses after reinforcement and then runs briefly at a relatively high rate (as at *a*, *b*, and *c*). As the session proceeds, the pause after reinforcement followed by an abrupt shift to rapid running becomes more pronounced. Although the grain of the record is quite rough, there are a few examples of reasonably good interval scallops (as at *e*, *f*, and *g*). In general, however, running declines during the latter part of each interval, occasionally with a fairly smooth deceleration (as at *h*, *i*, and *j*).

Figure 1. Rat 23. Cumulative curves of running in a wheel on FI 5. Curve B was obtained 4 days after Curve A. At this time the food used as reinforcement was inadequate.

Figure 2. Rat 23. Cumulative curve of running in a wheel on FI 5. Complete first session after change to an effective reinforcer. See text for explanation of letters.

Figure 3 shows a somewhat similar performance for Rat 7 for the second session after the change to palatable food. The burst of rapid running following the pause after reinforcement is exceptionally marked (as at *a*, *b*, *c*, and *d*). Except for these bursts of rapid running the over-all rate of running is low. Similar bursts of running following a pause after reinforcement were obtained when a rat operating a lever

Figure 3. Rat 7. Cumulative curve of running in a wheel on FI 5. Second session with an effective reinforcer.

under fixed-interval reinforcement had access to a running wheel (Skinner & Morse, 1957). The bursts of rapid running seen in Fig. 2 and 3 may be the kind of concurrent activity found in the earlier experiment. The running is clearly related to the schedule of reinforcement, and in some sense is dependent upon reinforcement; but possibly little if any of the running shown in Fig. 3 can be attributed to the conditioning of running under fixed-interval reinforcement.

The bursts of rapid running shown in Fig. 2 and 3 were a transient phenomenon, however, and performances more characteristic of fixed-interval reinforcement in other situations soon developed. Figure 4 shows the performance of Rat 23 twelve sessions after Fig. 2. By this time the procedure of having the rat in the wheel for 30 minutes before and after the period of fixed-interval reinforcement was in effect.

Figure 4. Rat 23. Cumulative curve of running in a wheel on FI 5. The session begins and ends with a period of nonreinforcement.

The twelve segments in the figure were recorded continuously. The two segments in the upper-left corner show the low over-all rate of running in the wheel in the absence of the discriminative stimulus for fixed-interval reinforcement. Between *a* and *e* the discriminative stimulus for the period of fixed-interval reinforcement was present and 40 reinforcements were given. In general, the performance is characteristic of fixed-interval reinforcement, with a pause after reinforcement followed by acceleration in running up to a relatively high rate (as at *b*, *c*, and *d*). In many intervals, however, the rate declines slightly just prior to the end of the interval. When the light was turned off at *e*, little running occurred during the remaining part of the session.

The decrease in running near the end of the interval was quite marked at times. Figure 5 is the performance for the same rat about 50 sessions after Fig. 4. In the interim the friction against which the wheel turned had been varied from 20 to 100 grams, and had been 30 grams for about a month prior to the session shown in Fig. 5. Initial running in the wheel without reinforcement is recorded between *a* and *b*. The interval performances are characterized by marked pauses after reinforcement, a relatively abrupt increase to a high rate of running, and then a decrease in running at the end of the interval. In many instances the decrease in rate is rather sudden (as at *c* and *d*), although more gradual decelerations in running appear in some intervals (as at *e* and *f*). After the light was turned off at *g*, no unreinforced running occurred.

Figure 5. Rat 23. Cumulative curve of running in a wheel on FI 5 showing deceleration in running at the end of the interval.

Figure 6 shows a sample performance for Rat 7 obtained with a friction of 30 grams. The segment between *a* and *b* gives the initial unreinforced running. In some instances, responding during the period of fixed-interval reinforcement resembles that obtained when a rat presses a lever on a fixed-interval schedule (as at *c*, *d*, and *e*), with a gradual increase in responding up to a sustained terminal rate, although occasionally an abrupt shift to steady running is followed by a subsequent decline (as at *f* and *g*). At *h* the light was turned off and some unreinforced running occurred during the next 30 minutes.

Figure 6. Rat 7. Cumulative curve of running in a wheel on FI 5: Deceleration in running occurs in some of the intervals.

The deceleration in responding toward the end of the interval might be due to investigatory responses to the food magazine. The rat may frequently stop after a short run to explore the magazine. Head movements toward the magazine are often observed when one watches a pigeon responding on a fixed-interval schedule of reinforcement, but such behavior is not sufficiently incompatible with responding to decrease the rate. In the case of running in a wheel, however, such magazine behavior would require that the animal stop running and turn toward the magazine. The occurrence of such behavior would result in a lower rate of running. Possible evidence for this is seen in the performance for Rat 7 in Fig. 7, where the terminal rates of running are sufficiently low so that the magazine could be explored without producing a further decrease in rate and where no decrease in responding is ob-

Figure 7. Rat 7. Cumulative curve of running in a wheel on FI 5. The force required to turn the wheel was greater than 50 grams.

tained. This performance was produced by requiring a considerable force to turn the wheel.³ As usual, the session begins with a period where running was allowed to occur unreinforced. Between *a* and *d*, running was reinforced on a fixed-interval schedule in the presence of the light. Typically, there is a pause after reinforcement, followed by a gradual increase in responding up to a terminal rate which is then maintained without any decrement. Especially smooth interval scallops are shown at *b* and *c*. At *d* the light is turned off and only occasional erratic running follows.

The effect of changing the force required to turn the wheel is shown in Fig. 8 and 9. The two records were obtained on the same day; Fig. 8 is for Rat 7, Fig. 9 is for

Figure 8. Rat 7. Cumulative curve of running in a wheel on FI 5. The wheel turned against a friction of 25 or 45 grams, as indicated on the record.

Rat 23. In Fig. 8, with an arbitrary friction of 25 grams, there is a high rate of unreinforced running between *a* and *b*. When the light designating the fixed-interval procedure is turned on, the friction is changed to 45 grams. Pauses generally occur after reinforcement, and the terminal rate is low. At *c* the friction is changed back to 25 grams. Now, a short pause follows reinforcement and then running occurs at a high rate. At *d* the friction is again increased to 45 grams and during the next four

³No exact calibrations were made of the force required to turn the wheel during this phase of the experiment. The force was between 50 and 100 grams.

Figure 9. Rat 23. Cumulative curve of running in a wheel on FI 5. The wheel turned against a friction of 25 or 45 grams, as indicated on the record.

intervals there is a longer pause after reinforcement and a low rate of running. The friction is decreased to 25 grams at *e* and increased to 45 grams at *f*. At *g* the light designating the fixed-interval procedure is turned off and the friction is changed to 25 grams. Unreinforced running occurred as shown. Performances on the fixed-interval schedule differ for high and low frictions. The pause after reinforcement is slightly longer and there was much less running at the higher friction than at the lower. Also, with the higher friction the rate increases slightly during the interval, but at the lower friction the rat immediately begins to run at a high rate. In general, these findings are confirmed by the performance of the other rat, shown in Fig. 9. Unreinforced running occurs prior to *a* and after *b*, against a friction of 25 grams. The fixed-interval performance when the friction was 25 grams is similar to that described earlier. There is a pause after reinforcement, an increase in rate of running, and then a subsequent decline in rate. At the higher friction there is no deceleration in running, where the terminal rate is possibly too low to show interruptions to explore the magazine.

A final point of interest is that reinforcement sometimes suppresses the rate of running below the unreinforced rate. In Fig. 7, the pauses after reinforcement are longer than any pauses occurring during the unreinforced running period prior to *a*. Another example of this effect is shown in Fig. 10. This record, for Rat 7, was obtained about 30 sessions after Fig. 6. The friction against which the wheel turned had been 30 grams for about 50 sessions. At this time the unreinforced running was substantial, both before and after the period of fixed-interval reinforcement in the presence of the light. Initial running in the absence of the light is shown between *a* and *b*. Following an initial pause at *a*, the rat alternately runs rapidly and pauses. After the onset of the light, the momentary rate of running under fixed-interval reinforcement is approximately the same as the unreinforced rate of running, except that a long pause follows each reinforcement (as at *c*, *d*, and *e*). Following each pause, there is an abrupt shift to sustained running which occasionally declines slightly near the end of the interval. When the light is turned off at *f*, there is an initial pause followed by rapid running with brief pauses.

Although reinforcing the animal on a fixed-interval schedule may not greatly change the momentary rate of running, it makes the behavior orderly with respect

Figure 10. Rat 7. Cumulative curve of running in a wheel on FI 5. Considerable running occurs during the periods of nonreinforcement at the beginning and end of the session.

to the schedule of reinforcement. This is clearly seen in Fig. 11, which gives the extinction of reinforced running during the session immediately following that shown in Fig. 10. This session began with the usual procedure. The segment between *a* and *b* shows running in the absence of the light. When the light came on (at *b*), the fixed-interval procedure was in effect until *c*. Thereafter, no running was reinforced although the light remained present. Following the usual pause after *c*, sustained running is maintained with very few pauses until *d*. Longer pauses then appear more frequently, until at *e* a pause of about 6 minutes is seen. By this time the effect of the fixed-interval contingency has largely disappeared. In this situation the extinction of reinforced running reveals itself as a gradual increase in erratic running and pausing.

Figure 11. Rat 7. Cumulative curve of running in a wheel. Extinction after FI 5.

SUMMARY

Fixed-interval reinforcement of running in a wheel generates a pause after reinforcement even when considerable running occurs in the same wheel before and after the experimental session. Other characteristics of the interval performance depend upon the friction against which the wheel turns and the resulting rate of running. In general, the rate of running decreases as the force required to turn the wheel increases. It is possible to find a friction such that the resulting fixed-interval performance resembles that obtained when a rat presses a lever under fixed-interval reinforcement.

In many instances, however, fixed-interval reinforcement of running in a wheel produces a curve which is negatively accelerated just before reinforcement. Since this is particularly true when the rate of reinforced running is high, it may be due to the competing behavior of exploring the food magazine.

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