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RESPONSE ACQUISITION AND FIXED-RATIO ESCALATION BASED ON INTERRESPONSE TIMES IN RATS

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The effectiveness of a fixed-ratio (FR) escalation procedure, developed by Pinkston and Branch (2004) and based on interresponse times (IRTs), was assessed during lever-press acquisition. Forty-nine experimentally naïve adult male Long Evans rats were deprived of food for 24 hr prior to an extended acquisition session. Before the start of the session, three food pellets were placed in the magazine. Otherwise, no magazine training, shaping, nor autoshaping procedure was employed. The first 20 presses each resulted in the delivery of a 45-mg food pellet. Then, the FR increased (2, 4, 8, 11, 16, 20, 25, 30) when each IRT in the ratio was less than 2 s during three consecutive ratios. Sessions lasted 13 hr or until 500 pellets were earned. On average, rats reached a terminal ratio of 11 (mean) or 16 (median) during the first session. Seven rats reached the maximum value of FR 30 and only one rat did not acquire the response. In most rats, a break-and-run pattern of responding characteristic of FR schedules began to develop in this acquisition session. Subsequently, the ratio-escalation procedure continued during daily 2-hr sessions. In these sessions, the starting ratio requirement was set at the terminal ratio reached in the previous session. Using this procedure, over half (26) of the rats reached the FR 30 requirement by the fourth session. These data demonstrate that a ratio-escalation procedure based on IRTs provides a time-efficient way of establishing ratio responding.

Key words: acquisition, fixed-ratio stretching, interresponse time, lever press, rat

A long-standing finding in the experimental analysis of behavior is that food-deprived rats readily acquire a lever-press response for appetitive reinforcement without any formal response shaping (e.g., Skinner, 1938). To facilitate response acquisition, however, habituation, magazine training, and some form of shaping have been widely used in past studies (for a review, see Gleeson, 1991). Habituation consists of initially exposing the rat to the operant chamber with no programmed contingencies in effect in an effort to allow for adjustment to its new surroundings. During magazine (feeder) training, the rat is provided the experience of eating food pellets out of the food receptacle. Often a stimulus (e.g., a tone) is paired with pellet delivery. Initially, food pellets are delivered by the investigator when the rat is near the magazine. Once the rat is eating reliably, food pellets are delivered only when the rat is away from the magazine. Training continues until the rat reliably approaches the magazine and eats whenever a pellet is delivered. Ferster (1953) and others have emphasized that magazine training facilitates subsequent response acquisition.

Lever-press responding is usually established following magazine training via shaping by successive approximations or autoshaping. Using shaping by approximations, the investigator differentially reinforces successive approximations to the lever-press response (e.g., orientating toward the lever, approaching, sniffing, touching, and finally pressing the lever). This approach requires an active role on the part of the investigator. Alternatively, an autoshaping procedure (Brown & Jenkins, 1968) may be employed which eliminates the active role of the investigator (for a review of the autoshaping procedure, see Schwartz & Gamzu, 1977). Autoshaping, or sign-tracking (Hearst & Jenkins, 1974), involves establishing contact with a conditioned stimulus through its association with a usually appetitive uncon-

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ditioned stimulus. Autoshaping procedures used to establish lever pressing in rats often are based on a procedure developed by Atnip (1977). This procedure consists of extending a retractable lever into the operant chamber for a short period of time (e.g., 10 s). At this point, a pellet is delivered and the lever is retracted for an intertrial interval (ITI) of some longer duration (e.g., 40 s). After a number of pairings between lever insertion and food, rats begin to approach and activate the lever, at which point control of food delivery is transferred to a continuous reinforcement schedule.

Once lever-pressing is acquired, responding on fixed-ratio (FR) schedules of reinforcement can be established by increasing the response requirement in small steps either within or across daily sessions. Lattal (1991) provides a description of a typical procedure used to increase the response requirement. Initially, responding is maintained on a continuous reinforcement schedule for at least several reinforcer deliveries. Then, the response requirement is increased in small steps (initially by one or two responses) for the remainder of the session. At the beginning of the next session, the response requirement is often lowered slightly to foster contact with reinforcer delivery, but is raised rapidly in larger increments (e.g., five responses) than in the previous session. Across several sessions, the response requirement is increased by progressively larger increments, although care must be taken not to increase the ratio too quickly, as this may result in ratio strain and the subsequent extinction of the response.

''Stretching the ratio'' (Skinner, 1968) requires a number of sessions and the active participation of the investigator. Pinkston and Branch (2004) developed an alternative, automated procedure for increasing ratio requirements based on animals' performance. In their study, pigeons previously trained to key peck using an autoshaping procedure were exposed to an FR 2 schedule of reinforcement. When the interresponse time (IRT; the time between two consecutive responses) was less than 1 s for four consecutive ratios, the ratio requirement was increased to 4. Thereafter, whenever subjects completed a ratio in which each IRT in the ratio (excluding the postreinforcement pause) was less than 1 s, the ratio was again increased according to a predetermined sequence, reaching a terminal ratio of 100.

The procedure developed by Pinkston and Branch (2004) is advantageous because the ratio automatically escalates only after animals complete it in a single run of responses (i.e., with minimal time between consecutive responses). This minimizes the chance that ratio strain will occur and eliminates the need for the investigator to play an active role in manually increasing the response requirement. In addition, this procedure may establish responding at high ratio requirements more quickly than traditional procedures that increase the ratio in small steps across daily experimental sessions.

Pinkston and Branch's (2004) procedure has yet to be critically evaluated or replicated in a different species. Indeed, this procedure is mentioned only briefly in the preliminary training section of their report, and was not the focus of their study. In the present study, we employed Pinkston and Branch's ratio-escalation procedure during lever-press acquisition for food reinforcers in experimentally naïve rats. We wanted to evaluate whether this procedure would serve as an effective method for rapidly establishing ratio responding.

Method

Subjects

Forty-nine, experimentally-naïve, male Long Evans rats (Charles River, Wilmington, MA) served as subjects. Subjects were approximately 90-120 days old and weighed between 388 and 514 g prior to beginning food restriction. Rats were individually housed in a temperature- and humidity-controlled vivarium on a 12-hr reverse light–dark cycle. With the exception of the initial acquisition session, daily sessions occurred during the dark portion of the cycle, when rats normally are active. The housing and care of subjects were in accordance with the ''Guide for the Care and Use of Laboratory Rats'' (Institute of Laboratory Animal Resources on Life Sciences, National Research Council, 1996). Further, animals were housed and all experiments were conducted in an AAALAC accredited facility.

Upon arrival to the facility, rats were given ad libitum access to food and water prior to the study. Prior to the acquisition session, a free-feeding weight and a target weight (85% of the free-feeding weight) were determined

for each rat. For 31 rats, food was gradually restricted for approximately 5 days prior to the acquisition session. For the remaining 18, food was not restricted during this time. All rats, however, were food deprived for 24 hr immediately preceding the acquisition session. The difference in the feeding regimen was unintended and the result of a change in the personnel conducting the study. Overall, 10 rats were within 10 g of their target weights immediately prior to the acquisition session, while the remaining rats were overweight. Following the acquisition session and thereafter, supplemental food was provided if rats' body weights dropped 5 g or more below target, and occurred approximately 30 min after the end of daily sessions.

Apparatus

Eight commercial operant chambers (30 cm × 24 cm × 20 cm; ENV-008CTX; Med-Associates, St. Albans, VT) were used. Each chamber was enclosed in a sound-attenuating cubicle equipped with a ventilation fan and contained two retractable levers (ENV-112CM), a house light, a food-pellet dispenser, and a food-pellet receptacle centered beneath the two levers. Only the right lever was used in this experiment. A hole was cut in the top Plexiglas ceiling of each chamber to allow for the insertion of a water bottle. Water was always available both during the experimental sessions and in home cages.

Procedure

The initial acquisition session commenced 24 hr after food had been removed from the rats' home cages. Forty-five-mg food pellets (Noyes, Lancaster, NH) served as reinforcers during the study. Three pellets were placed in the food receptacle at the onset of the session and no magazine training or shaping of any kind was used. The onset of the session was signaled by the illumination of the house light and the insertion of the right lever into the chamber. When a lever press occurred, the lever retracted, a single food pellet was delivered, and the lever was immediately reinserted back into the chamber. An FR 1 schedule was in effect until 20 reinforcers had been delivered, at which point the schedule changed to an FR 2. The ratio subsequently was increased (4, 8, 11, 16, 20, 25, 30) whenever rats completed three consecutive ratios in which each IRT in the ratio (excluding postreinforcement pauses) was less than 2 s. The session lasted for 13 hr or until rats earned 500 reinforcers.

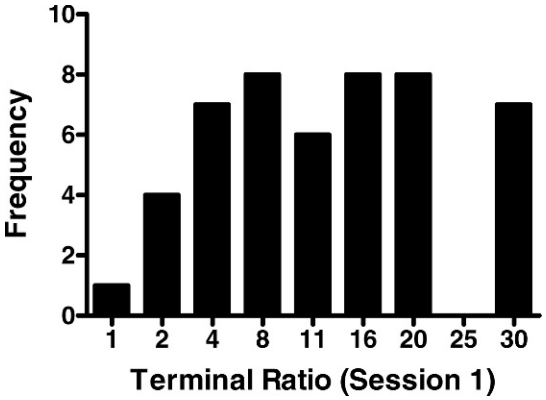

Fig. 1. Frequency distribution of the terminal ratios reached during the initial acquisition session.

Following the acquisition session, daily 2-hr sessions were conducted using the same escalation procedure. The ratio reached at the end of any given session was used as the starting ratio at the beginning of the next session. Once the FR 30 schedule was reached, an additional five sessions were conducted at this schedule value.

Results

The lever-press response was considered acquired when 20 responses had been emitted. Only one rat failed to meet this criterion. This rat earned seven pellets in the session at an FR 1. Thirty-seven rats acquired the response within the 1st hr of the session and only 6 required longer than 3 hr. Excluding the rat who failed to acquire the response, no significant relationships were found between response acquisition time (in minutes) and deviation from (i.e., grams over) target body weight ($r = -.02$, $p = .88$) or the ratio reached in the acquisition session ($r = -.09$, $p = .54$).

The ratio values reached (terminal ratios) in the acquisition session, expressed as a frequency distribution, are shown in Figure 1. The mean terminal ratio was 11 and the median value was 16. Seven rats reached the maximum ratio of 30. The relationship between the deviation from target weight and the terminal ratio was not significant ($r = -.19$, $p = .18$).

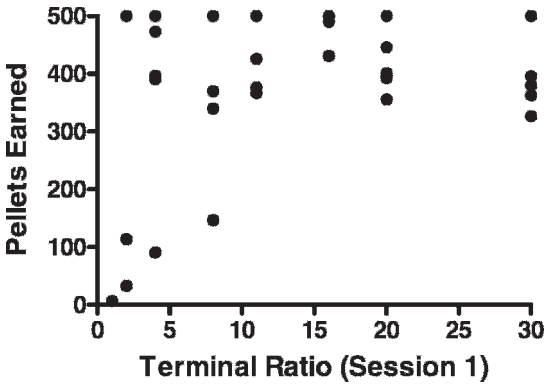

Fig. 2. Scatter plot of the number of pellets earned during the initial acquisition session as a function of the terminal ratio reached during that session.

Figure 2 shows the relationship between the number of pellets earned and the terminal ratio in the acquisition session. The 5 rats that earned substantially fewer pellets than the others also had low terminal ratios, resulting in a positive correlation between the terminal ratio and the number of pellets earned which approached statistical significance ($r = .26$, $p = .07$). It is important to keep in mind that it was quite possible for rats to earn the maximum of 500 pellets without advancing the ratio beyond an FR 2. The correlation between total pellets earned and the deviation from target weight also approached statistical significance ($r = -.24$, $p = .09$). There was a slight tendency for overweight rats to consume fewer pellets.

Inspection of cumulative records revealed that, across the acquisition session, rats tended to respond in bursts, punctuated by long periods of no responding. Figure 3 shows representative cumulative records from 3 rats that reached ratios of 8, 16, and 30. Shown is a 10-min segment taken from the last major response burst of the session. A break-and-run pattern of responding characteristic of FR schedules (Ferster & Skinner, 1957) can be observed, with a pause following reinforcer delivery followed by a high response rate until the next reinforcer was produced.

The left axis of Figure 4 shows the terminal ratio (mean ±SD) reached across sessions. The right axis shows the cumulative percentage of rats reaching the FR 30 criterion across sessions. Only six sessions are shown because the rats who reached the FR 30 criterion in the acquisition session only experienced six total sessions in this study. The mean terminal ratio increased steadily between sessions 1 and 6. By the fourth session, over half of the rats (26) had reached an FR 30, and by the sixth session, 36 of 49 had reached this value. Rats requiring longer than six sessions to reach the FR 30 requirement usually completed several consecutive sessions without meeting the IRT requirement for advancement. The longest number of sessions required to reach the FR 30 criterion was 14.

Discussion

Conventional methods for establishing lever pressing in rats consist of habituation to the operant chamber, magazine training, and shaping by approximations or autoshaping. While it has long been known that these steps are not necessary in order for rats to acquire the lever-press response (e.g., Skinner, 1938), these procedures can facilitate response acquisition (Gleeson, 1991). The actual degree to which they do so, however, is not known. The results of this study show that many rats are able to acquire (relative to our criterion) a lever-press response within 1 hr, even in the absence of explicit magazine training and response shaping. Of course, this finding does not suggest that preliminary training procedures never have a useful role. Magazine training, for example, undoubtedly is critical when there is a limited hold on the availability of the reinforcer, as is the case when the reinforcer is delivered via a hopper or dipper. Shaping by approximations may be desirable when the number of animals to train is few and the time allotted for acquisition is brief, or when it is critical to shape a precise response topography. Autoshaping procedures may be warranted when the number of animals to train is large and it is important to hold constant the number of reinforcer presentations (Gleeson, 1991).

Moreover, restriction of body weights to a conventional level (e.g., 85% of free-feeding weight) does not appear necessary before conducting the acquisition session. A limited (24 hr) food-deprivation regimen followed by a 13-hr session resulted in response acquisition for almost all rats. It may be unnecessary to spend several days or weeks food-depriving rats to a target weight, followed by habituation, magazine training, and response shaping

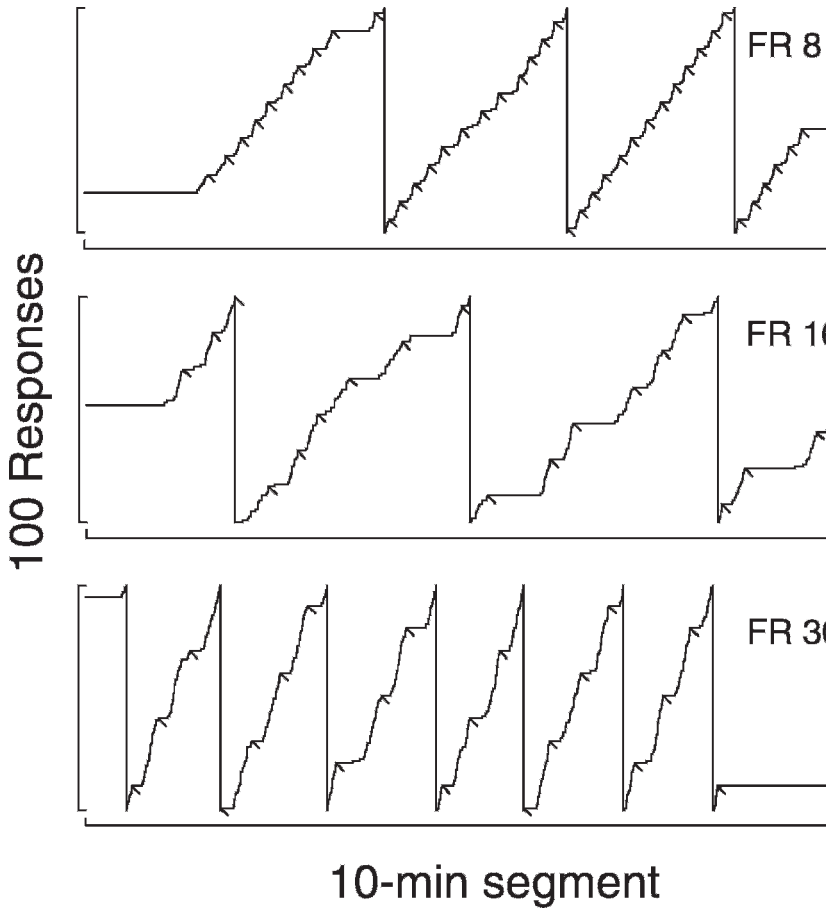

Fig. 3. Segments of representative cumulative records from the initial acquisition session for 3 rats reaching ratios of 8, 16, and 30. Each record represents a 10-min period from late in the session.

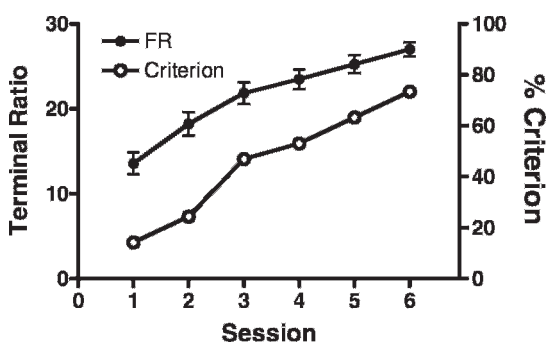

Fig. 4. Mean ratio reached as a function of session (left axis). Error bars represent standard deviations. Cumulative percentage of rats reaching the FR 30 schedule requirement as a function of session (right axis).

procedure if the goal of preliminary training is simply response acquisition and ratio stretching.

The ratio-escalation procedure evaluated here is similar to the targeted percentile schedule advocated by Platt (1973) and Galbicka (1994) as a means to formalize the shaping process. Under a targeted percentile schedule, a response produces a reinforcer only if it is a certain percentage closer to a target response. For example, Galbicka, Kautz, and Jagers (1993) arranged a procedure in which rats' right lever presses initially were reinforced after at least one press on the left lever. Subsequently, a target of 12 left- lever presses was established. A right-lever press was

reinforced only if the run of left- lever presses preceding it was nearer to the target than 67% of the previous 24 runs. Runs of left lever presses approximated the target value within twenty 30-min sessions.

In both the ratio-escalation procedure and percentile schedules, the reinforcement criteria change was based on some aspect of behavior. The ratio-escalation procedure takes advantage of the fact that ratio schedules by nature differentially reinforce short IRTs (Ferster & Skinner, 1957; Morse & Kelleher, 1977). Within some ratio parameters, there exists a positive feedback loop between responding and the ratio requirement. As a result of the schedule differentially reinforcing short IRTs, the ratio increases, functionally increasing the probability that short IRTs will continue to be reinforced, resulting in further increases in the ratio. As a result of this positive feedback loop, perhaps, the break-and-run pattern of responding characterized by FR schedules (Ferster & Skinner, 1957) quickly appeared in this study.

Nevertheless, it is not yet known if this procedure actually establishes ratio performance any faster than traditional procedures. Comparing the speed of FR stretching between this and conventional procedures is difficult because investigators typically do not provide enough detail in their descriptions of preliminary training—either in terms of the FR increments or the number of sessions conducted—to make a meaningful comparison. However, it is possible to compare our results with those obtained using targeted percentile schedules. The mean terminal ratio in our initial acquisition session was 11, which approximated the average run length Galbicka et al. (1993) established in 20 sessions. When equated for exposure to the schedule (Galbicka et al. used 30-min sessions), the results are comparable. Regardless of whether or not the ratio-escalation procedure establishes ratio performance more quickly than traditional procedures, it remains attractive for several reasons. First, it establishes responding at moderate ratio requirements over the course of a single (or a few) fairly long session(s), much more quickly (from the perspective of the investigator) than traditional procedures. Second, reliable responding is acquired without the need for the active involvement of the investigator. Further, response requirements can be titrated according to the performance of individual subjects, decreasing the likelihood that ratio strain will occur.

Several methodological details regarding the ratio-escalation procedure warrant comment. First, we employed a slightly more liberal IRT requirement than what Pinkston and Branch (2004) used in pigeons. We initially applied their IRT requirement (1 s) in several pilot rats, but found that the rats did not consistently advance the ratio. In addition, we do not yet know if the IRT requirement chosen for this study is the most optimal one for quickly establishing ratio performance. Indeed, in some cases it seemed too conservative. Figure 2 shows that some rats that only reached low terminal ratios during the acquisition session still acquired close to 500 pellets. While a more relaxed IRT requirement might allow for faster escalation, it also could result in ratio strain. In addition, after acquisition, a number of rats reliably earned food pellets according to a particular ratio, but spent three sessions at this ratio before advancing it. Using the ratio-escalation procedure, it is possible for rats to become ''stuck'' at a particular response requirement, and the IRT requirement must then be relaxed or the FR simply increased by the investigator. Future research might explore the effects of varying IRT requirements on ratio escalation and response patterning.

The use of a retractable lever seems critical for the effectiveness of the ratio-escalation procedure. Early in training, and especially in the absence of magazine training, rats have a tendency to overrun the ratio. That is, when a reinforcer is delivered, rats may make several additional lever presses in the next ratio before collecting the food pellet. This behavior results in a long IRT during the ratio and prevents the ratio from escalating. We observed this phenomenon in several other pilot rats studied using a nonretractable lever. Retracting the lever during reinforcer delivery prevented this problem.

The ratio-escalation procedure originally developed by Pinkston and Branch (2004) and further extended to rats in the current study will be a useful approach for investigators who need to establish ratio responding quickly in experimentally-naïve animals. The procedure may be a particularly valuable way to decrease training time when the species

under investigation has a short lifespan (e.g., mice) or when aspects of the research impose time constraints (e.g., the duration of catheter patency in drug self-administration research).

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