LABORATORY SYSTEMS AND COMPUTER SIMULATIONS

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An auto-adjusting shaping procedure

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A variable interval (VI) schedule is described that automatically adjusts the programmed rates of reinforcement in accordance with the rates of responding of subjects during the two immediately preceding 30-sec time intervals. The schedule prescribes that as rate of responding decreases, programmed reinforcement rate increases, and that when rate of responding increases, reinforcement rate decreases. Thus, programmed reinforcement rate is adjusted continuously until some target value is reached. Ten rats were exposed to this procedure five times a day at 1-h intervals. The target, set at VI 120 sec, was reached by most subjects within 4 days of training. Subsequently, all subjects responded consistently during five daily 1-h sessions with VI 120 sec. This procedure speeds up the training of subjects on long VI schedules and substantially reduces the time and effort spent observing the subjects and adjusting the schedule parameter value during the early development of responding.

Experiments concerning independent variables that affect stable operant responding in animals usually involve procedures in which responding is maintained by infrequent presentations of the reinforcer, and in which rate of reinforcement is relatively insensitive to changes in response rate. For these purposes, one of the more commonly used procedures is the variable interval (VI) schedule of reinforcement. A VI schedule prescribes that a reinforcer will be presented following a response that occurs after some time interval t since the previous reinforcer presentation. The value of t varies unpredictably from trial to trial, and its average duration is the parameter of the schedule. Thus, a VI 120 sec prescribes that, on the average, reinforcers will become available 120 sec after the preceding reinforcer presentation. With rats as subjects, it is often difficult and time-consuming to develop stable response rates under such low-density VI schedules of reinforcement. The usual training procedure consists of shaping the hungry rat to press the bar by giving it food for successive approximations to the desired response. Once the barpress response is acquired, the rat is exposed to a high-density schedule of food presentation such as a VI 5 sec. After a session or two, when it is

clear that the rat is responding consistently, the value of the schedule is again increased. Thereafter, progressively larger values of the schedule are introduced every few sessions until the desired final value is reached. Responding sometimes deteriorates during development, and the schedule's value must be decreased for a while before larger values can again be introduced. If the desired baseline schedule is VI 120 sec, this process can take as long as several weeks and requires consistent monitoring of the rat's behavior in case the animal stops responding.

The path of development of the response baseline has typically not been of interest in experiments that concern the effects of drugs and other variables on operant responding. But, since the experiments sometimes require that all the animals be exposed to the independent variable (drug administrations) simultaneously, the initiation of the experimental manipulation has to wait until every rat in the experimental group reaches the response stability criterion. Therefore, any procedure that produces rapid adjustments to low-density schedules of reinforcement and stable baseline performance is desirable. This paper describes a method that substantially reduces the time, effort, and vigilance required to establish consistent responding in rats under VI 120-sec schedules of food presentation. The method involves two independent features: (1) automation of the process of increasing the value of the schedule when responding shows no signs of deterioration, or decreasing it when responding deteriorates. This eliminates the need for human monitoring of the animal's behavior during performance development

This research was supported in part by grants to J.M.S. and F.A.G. from the National Institute on Drug Abuse (MIRDP-5R24DA07256-04) and the National Institutes of Health (MBRS-1S06GM45913-2). Correspondence should be addressed to J. M. Stahl, Department of Psychology, Morris Brown College, 643 M. L. King, Jr. Dr., Atlanta, GA 30314 (e-mail: mbcmird@ix.netcom.com).

and reduces the subjectivity involved in the decisions about the readiness of the animal to move to the next, higher, value of the schedule. (2) Conducting several sessions per day. The number of days required to reach the desired baseline schedule value can be reduced considerably by conducting multiple sessions each day. In addition, shaping behavior during the night allows for more efficient use of research equipment and research technicians' time.

METHOD

Five male and five female naive Long-Evans hooded rats, maintained at 85% of their free-feeding weight, were initially hand-shaped to leverpress in standard Coulbourn operant conditioning chambers connected to a PC through a Med Associates interface. The auto-adjusting shaping program shaped the animals' leverpressing performance from a VI 1-sec to a VI 120-sec value over several overnight sessions. Each daily session consisted of five work periods separated by 1-h rest periods. The test chamber light was off during the rest periods and illuminated when the VI schedule was in effect. The start of each work period was signaled by illuminating the chamber light, buzzing a feedback clicker for 5 sec, and delivering a food pellet. Each of a series of five work periods involved exposure to the auto-adjusting VI schedule and ended after 20 reinforcements were earned (45-mg Bio-Serv pellets). The feeder lamp was illuminated 0.5 sec before reinforcement delivery, and remained on for 5 sec. During these periods the houselight was turned off, the schedule was interrupted, and a water dipper was raised to provide access to 0.05 ml of water. The sequence of five successive work periods was a modifiable feature of the computer program. The data were recorded separately for each 30-sec interval. Values of the relevant procedure parameters and response variables were automatically carried from one work period to the next.

Although the program was written in Med State notation, this is not a necessary feature of the program. Thus, only the general properties of the program are described here. At the beginning of a series of sessions, the experimenter set the VI value to the final value of the last session of the previous day (the first session was set at VI 10 sec). The program calculated the mean response rate every 30 sec throughout each 1-h session. At the beginning of each 30-sec interval, within a 1-h session, the program checked to determine if the subject had just finished a 1-h break. If so, it set the VI value to the ending VI value of the previous session or the final criterion value (VI 120 sec), whichever was lower. If not, it checked to see if the average response rate of the animal for the two preceding 30-sec intervals was lower, higher, or equal to the mean response rate of the entire session to that point. The program then decreased or increased the VI value a proportion of the current VI value. (1) If the response rate at the end of the immediately preceding two 30-sec intervals was 90% or greater than the average for the entire session, the VI value was increased. If not, the animal's VI was adjusted to a VI that was proportionate to its previous VI value. (2) If the animal's response rate at the end of the immediately preceding two 30-sec intervals was not 90% or greater than the previous response rate, the program asked if the response rate was less than or equal to 70% of the previous response rate of the animal. If so, the program decreased the VI value by a proportion of the current VI value. (3) If the animal responded between 71% and 89% of the average response rate for the session, the program kept the current VI level for the next interval.

The formula by which the program decreased or increased the VI value is an algebraic expression that generated values falling along an S-curve. This was thought to be a good function to set the adjusting level of the animals because of the slow, gradual increase at the beginning of the curve; as the value increased to a certain

value, the increase becomes a little faster. Then, as the VI is nearing its criterion level, the increase becomes slow and gradual again. This function holds true for any VI level that one wants to achieve. However, we feel that simply increasing or decreasing the VI value by a fixed amount at each decision point (5%–10% of the previous VI value) would achieve satisfactory results.

RESULTS

The second column in Table 1 presents the time in minutes spent by each rat on the auto-adjusting schedule before reaching the VI 120-sec criterion. The third and fourth columns present the means and standard deviations of the daily response rates for each rat during five 1-h sessions at VI 120 sec. Seven rats reached the target value in less than 10 h (2 days). Rats 1167, 1169, and 1172 did not always respond during the later work periods of the sessions. Therefore, it took them much longer to reach criterion. Only Rat 1169 failed to reach the VI 120 sec on its own. All rats responded consistently when exposed to standard VI schedules.

Within 7 consecutive days of exposure to the schedule, 9 of the 10 rats progressed from VI 10 sec to VI 120 sec. Rat 1169 regularly stopped responding during the last two work periods of the sessions. Since its behavior pattern made it unlikely that it would reach criterion, the auto-adjusting schedule was stopped during the third work period of the fifth session, when the schedule parameter was 110 sec. Except for Rat 1169, once the rats were on the auto-adjusting VI schedule, experimenters never intervened until the 120-sec parameter value was reached. The second column in Table 1 presents the time in minutes required by each rat to reach the VI 120-sec criterion. Thereafter, the schedule was fixed at VI 120 sec and 1-h sessions were conducted during 5 consecutive days. As noted, Table 1 also presents the means and stan-

Table 1
Time Spent by Each Rat on the Auto-Adjusting Schedule Before Reaching the VI 120-Sec Criterion

Subject Numbers	Time on ADJ to VI 120 sec	Response Rate at VI 120 sec	
		<i>M</i>	<i>SD</i>
1166	202.05	8.83	1.07
1167	1598.12	7.75	2.58
1168	507.77	7.74	2.58
1169	712.08*	12.15	2.19
1170	313.90	30.60	5.77
1171	168.53	16.56	5.58
1172	1019.35	6.91	1.98
1173	550.97	6.49	.70
1174	217.57	36.22	11.13
1175	256.90	25.17	4.76

Note—Time in minutes spent by each rat on the auto-adjusting schedule (ADJ) before reaching the VI 120-sec criterion is shown in the second column. The third and fourth columns present the means and standard deviations of the daily response rates (responses/minute) for each rat during five 1-h sessions at VI 120 sec. Seven rats reached the target value in less than 10 h. Rats 1167, 1169, and 1172 did not always respond during the later work periods of the sessions; therefore, it took them much longer to reach criterion. Only Rat 1169 failed to reach the VI 120 sec on its own. All rats responded consistently when exposed to standard VI schedules. *Reached VI 110 sec only.

dard deviations of the response rates for the five VI 120-sec sessions. Although five 1-h sessions were insufficient to affirm that responding was stable, they were sufficient to indicate that responding was not deteriorating.

Mean response rates and mean VI values for 3 representative rats, during the consecutive work periods of each auto-adjusting session and during the five VI 120-sec sessions, are presented in Figure 1. Rats 1170 (panel A) and 1175 (panel C) responded consistently and rapidly reached the criterion VI. Rat 1172 (panel B) is representative of subjects that responded inconsistently when the VI schedule parameter reached large values. Note that by the end of the third session, Rat 1172 had reached VI 50 sec. Session 4 was started at this value and the response rate decreased during the first work period. Responding recovered during the second and third work periods, yielding a VI 100 sec, but it rapidly deteriorated during the fourth and fifth work periods and, as a result, Session 5 was started at VI 4 sec. During Session 5, Rat 1172 again responded more during the middle work periods and did not respond much during the later periods. Session 6 started with VI 5 sec. The rat responded at a high rate throughout, yielding a VI 76 sec by session's end. Responding was fairly consistent during the seventh session, and the criterion was finally reached during the fourth work period. Response rate for this rat during the five VI 120-sec sessions was low, but it was consistent, and long pauses from responding did not occur.

DISCUSSION

The described procedure facilitates the training of rats to respond under long VI schedules of reinforcement. Details of the procedure were developed through trial and error. In earlier versions of the procedure, for example, changes in the VI parameter value were based on comparisons between the response rate during only one 30-sec interval and the overall response rate. It was soon evident, however, that this comparison did not lead to consistent increases in the value of the schedule. Consequently, the requirement of unidirectional differences between overall response rate and the rate during each of two consecutive 30-sec intervals (rather than just one) was introduced. Since this modification of the program seemed to work, no further changes were made. We did not explore systematically the effects of changing these values in the formula. The values used in the present procedure, 0.9 and 0.7, were chosen, after unsystematic experimentation, because they seemed to work well enough. The same approach was followed to settle on the use of the function $P_{i+1} = P_i + P_i^2 (1 - P)$, which was chosen because it accelerates rapidly when P is close to zero, grows at a fairly constant rate as P increases through intermediate values, and finally decelerates slowly as P approaches 1. Since P is large when the schedule parameter is small, this function increases the VI value slowly during early development of responding, and progressively faster as the higher values are reached. Two other simi-

Figure 1. Mean response rates (filled squares) and mean VI values (open circles) for 3 representative rats during consecutive work periods of each auto-adjusting session, and during the five VI 120-sec sessions. By responding with sufficient consistency, Rat 1170 closed in on the VI 120-sec target during the second work period of the third session (panel A), and Rat 1175 reached the target VI value during the last work period of Session 4 (panel C). The performance of these rats is representative of that of most rats exposed to the procedure. Rat 1172 is representative of rats that responded inconsistently for a while when the VI value started to grow rapidly (panel B). The data clearly show that the program appropriately adjusted the VI schedule parameters as responding by Rat 1172 increased and decreased during the fourth and fifth sessions. When the rat finally responded more consistently after the 25th work period, the VI rapidly increased to criterion.

lar functions for adjusting the value of the schedule were also tried, but the above appeared to work better. There may well be other functions that work as well or better than the one we chose to employ and present here.

Scheduling five daily work periods at 1-h intervals seems to work well for most rats. It is also clear, however, that some animals quit responding before completing all five periods. We have not tried changing the duration of the rest periods, nor the deprivation schedule, nor any number of other factors that might affect the rats' disposition to respond during the later work periods. It is apparent, however, that reducing the number of work periods from five to three or less seems to work well with those rats that tend to quit responding during the later work periods of a long session.

The auto-adjusting VI schedule is used in our laboratory to rapidly and effortlessly train rats that will later be used in drug experiments, or in a 3-hour/week undergraduate student laboratory course on operant conditioning. We have found that about 90% of the rats exposed to the procedure can be essentially ignored until the VI criterion is reached. In fact, 5 of the rats that generated the data presented here (Rats 1171–1175) were placed in chambers at 5:00 p.m., sessions automatically started at 10:00 p.m.,

and the rats were taken out at 8:00 a.m. There was nobody around when the auto-adjusting VI sessions were taking place. Thus, the shaping procedure did not take up valuable daytime use of the research equipment and assistants.

We have not tried using this procedure to address current theoretical issues in operant conditioning. It seems to us, however, that given the right combination of procedure parameters, and if a limit were not placed on the maximum VI parameter value, then the attained asymptotic value of the VI schedule would reflect reinforcer effectiveness, response effort, motivation, and so on, and could be used in lieu of, for example, concurrent VI schedules, to study those and other independent variables. Future research will assess the efficiency of using a larger number of shorter daily sessions and focus on the development of a method for reducing between-subject variability in performance and accelerating the development of more stable baseline responding. In addition, a more formal comparison between this approach and the traditional hand-shaping method will be carried out.

(Manuscript received November 13, 1995;
revision accepted for publication February 19, 1996.)