A comparison of sequenced reinforcement under free-operant and discrete-trial contingencies*

ALLEN H. WOLACH† and DOUGLAS P. FERRARO
University of New Mexico, Albuquerque, N. Mex. 87106

Three experiments were performed to examine the effects of sequenced reinforcement on resistance to extinction. When Ss were given extended training in a free-operant lever chamber situation, single N-length (always the same number of nonreinforced leverpresses before a reinforced press) groups were at least as resistant to extinction as multiple N-length (number of nonreinforcements before a reinforcement varied) groups. In fact, when Ss experiencing N-lengths of 6 (six nonreinforcements before a reinforcement) were compared with Ss experiencing N-lengths of 2, 4, and 6, the single N-length groups showed greater resistance to extinction at all training levels. Groups that experienced discrete-trial (the lever retracted for 15 sec after every press) training showed greater resistance to extinction when they experienced multiple N-length sequences. The experiments supported Capaldi's sequential response hypothesis only when a discrete-trial procedure was used. Extended training did not produce greater resistance to extinction for multiple N-length free-operant Ss.

Recent conceptualizations of the partial reinforcement effect are more "dynamic" in nature than older existing theories. That is, rather than percentage of reward being the primary independent variable, present emphasis is laid on the sequence of occurrence of reinforced (R) and nonreinforced (N) responses (Capaldi, 1967; Schoenfeld, 1968).

Capaldi's (1964, 1967) sequential theory is representative of the dynamic approach. Since much of what follows can be taken as a test of Capaldi's theory in the free-operant situation, it is necessary to summarize some of the major points in the theory. The sequential theory employs N-length (number of successive nonreinforcements before a reinforcement) as the main determinant of resistance to extinction in partial reinforcement studies. Habit strength builds up to all of the N-lengths S is exposed to in his acquisition training. The habit strength for a given N-length generalizes to other N-lengths.

Early in training, habit strength is not at asymptote on any N-length in a sequence of partial reinforcement that contains one or more N-lengths. As training progresses, a S experiencing a sequence with fewer N-lengths approaches habit strength asymptote on each N-length faster than a comparable S who experiences a greater number of N-lengths. Thus, a S who is extinguished after a minimal

number of training trials and experiences very few N-lengths is more resistant to extinction than a S who receives a minimal number of training trials on many N-lengths.

When Ss receive enough training trials to reach habit strength asymptote on all N-lengths, they are more resistant to extinction if they receive training on many N-lengths than are comparable Ss who experience fewer N-lengths. Capaldi has noted that the above assumption can be tested only if the maximum N-length in both comparison groups is the same. This is because longer N-lengths are assumed to lead to greater resistance to extinction than shorter N-lengths. If the maximum N-lengths in the sequences being compared is not the same, it is impossible to ascertain if number of N-lengths or length of N-lengths (or both) contribute to differences in resistance to extinction.

Studies performed on sequenced reinforcement need not always produce similar results in the operant and instrumental situations. The present series of experiments was performed to determine if Capaldi's (1964, 1966) sequential response theory that was tested in the discrete-trial runway situation could predict resistance to extinction in the free-operant situation. In addition, the present investigators wanted to determine if possible differences in results were related to the operant vs instrumental distinction (presence or absence of an intertrial interval) or if the apparatus (runway or lever chamber) is the major determinant of differences in the available data.

EXPERIMENT 1

Subjects

Forty-eight naive female rats (150-200 days old) from the University of New Mexico colony served as Ss. The Ss were individually caged and maintained at 80% of their normal body weights by restricting their water intake. During the experiment, Ss were watered immediately after they completed their training or test session. The Ss experienced approximately 23½ h of water deprivation every day.

Apparatus

Four sound-attenuated operant chambers (Scientific Prototype Model A100) were used. A rectangular lever (5.08 x 2.54 cm), requiring 10 g of downward force, served as the manipulandum. The chambers were programmed by solid-state circuitry that arranged reinforcement contingencies. Reinforcement was delivered by water dippers (Lehigh Valley) that presented .02 cc of water for 3 sec.

Procedure

The Ss were placed in their operant chamber until they made 50 leverpresses. Each leverpress was accompanied by the appearance of the loaded water dipper. If S failed to make 50 leverpresses in 1 h, S was removed from the chamber for 1 h and then placed in the chamber again. All Ss made 50 leverpresses before 3 h of chamber time had elapsed.

The Ss were assigned randomly to one of two possible sequences for reinforcement. Equal numbers of Ss (eight) received reinforcement on one of the two sequences for 2, 4, or 8 days. A leverpress produced the dipper for 3 sec if the apparatus was programmed to reinforce the press. Trials that were not reinforced produced no cues when S pressed the lever. If S pushed the lever while the dipper was still in the reinforcement position, it immediately went down and remained down or came back up, depending on what was programmed in the sequence.

The sequences Ss experienced were the same as the sequences that Capaldi (1964) used (an N-length of 3 or N-lengths of 1, 2, and 3). Table 1 shows the sequences that were used.

All Ss remained in the experimental chamber until they went through their sequence four times. Consequently, on

Table 1
Reinforcement Sequences Employed in the First Experiment

N-Length 3	N-Lengths of 1, 2, and 3
RNNNRR	RNNNRR
RRNNRR	RRNNRR
NNNNRR	NNNNRR
RRNNRR	NRNNRR

*This research was performed under NSF Grant GB7674.

†Now at Illinois Institute of Technology, Chicago, Ill. 60616.

Fig. 1. Resistance to extinction for Ss experiencing an N-length of 3 or N-lengths of 1, 2, and 3.

a given day each S made 96 leverpresses and received 48 reinforcements. The time from the first leverpress to the last press was recorded. Cumulated time for the dipper in the reinforcement position was also recorded.

After S completed training on his sequence for 2, 4, or 8 days, extinction was initiated. All Ss experienced four extinction sessions on the 4 days following their last acquisition session. During extinction, S remained in the chamber for 14 min following his first leverpress. The number of leverpresses during the extinction session was recorded.

Results

The rate of responding for Ss on the last day of acquisition was compared. There was no difference in session time for Ss experiencing 2 days of training on the two sequences [$t(14) = .2$, $p > .05$], 4 days of training [$t(14) = 1.1$, $p > .05$], or 8 days of training [$t(14) = .6$, $p > .05$]. Since the response rate for a given number of days of training was the same for both sequences, it was possible to compare extinction data at a given training level without correcting for acquisition rate (Anderson, 1963).

Figure 1 shows the leverpresses during the 4 days of extinction for the Ss who experienced different numbers of days of training. The two sequences of reinforcement are compared at each training level. An analysis of variance (Days of Training by Sequence) revealed a significant effect of days of training [$F(2,42) = 9.1$, $p < .01$] and Days of Training by Sequence [$F(2,42) = 13.1$, $p < .01$].

The two sequences were then compared for their effects on resistance to extinction at each training level. The greater resistance to extinction for the single N-length group after 2 days of training is

significant [$t(14) = 4.3$, $p < .01$]. After 4 days of training, the multiple N-length group exhibited greater resistance to extinction [$t(14) = 3.5$, $p < .01$]. When Ss received 8 days of training, there was no difference in resistance to extinction for either sequence [$t(14) = 1.1$, $p > .05$].

The data obtained from Ss experiencing 8 days (384 reinforcements) of training cannot be explained by Capaldi's theory. Since Ss in the present study received more presentations of the sequences than Ss in Capaldi's runway study, it was possible that transitions [e.g., a reinforced press (R) followed by a nonreinforced press (N) is an R-N transition] could become important determinants of behavior after extended acquisition training. The Ss experiencing the sequence with three N-lengths experienced four R-R transitions, seven R-N transitions, four N-R transitions, and eight N-N transitions each time the sequence was completed. Two new sequences (N-lengths of 6, or 2, 4, and 6), in which Ss in both groups received approximately the same percentage of a given kind of transition, were produced. It was, of course, impossible to produce a multiple N-length sequence and a single N-length sequence that had an equal number of each kind of transition. The sequence with the N-length of 6 had 4 R-N, 19 R-R, 4 N-R, and 20 N-N transitions. The multiple N-length sequence (N-lengths of 2, 4, and 6) had 6 R-N, 17 R-R, 6 N-R, and 18 N-N transitions. Experiment 2 was performed to examine the effects of N-lengths with sequences that were nearly equated in number of each kind of transition. The two new sequences were obtained by doubling every R and every N in the sequences in Table 1; e.g., RNNNNRRRR became RRNNNNRRRR.

EXPERIMENT 2

Subjects

Forty-eight naive male albino rats from Simonsen Laboratories were used. They were kept under the same conditions as Ss in the first experiment.

Apparatus

The apparatus that was used in the first experiment was used in this experiment.

Procedure

The procedure was the same as the one employed in the first experiment, with the following exceptions: (1) The Ss in this experiment experienced N-lengths of 6 or 2, 4, and 6 instead of 3 or 1, 2, and 3. (2) All Ss went through their sequence two times on a given day. This enabled Ss to obtain the same number of reinforcements every day as Ss in Experiment 1. (3) In addition to Ss experiencing 2, 4, and 8

Fig. 2. Resistance to extinction for Ss experiencing an N-length of 6 or N-lengths of 2, 4, and 6.

days of training, Ss with 16 days of training were run. The two 16-day groups had as many experiences with their N-lengths as the two 8-day groups in Experiment 1.

Results

Rate of responding on the last day of acquisition was the same for Ss experiencing both sequences at a given number of days of training: after 2 days [$t(14) = .8$, $p > .05$], 4 days [$t(14) = .5$, $p > .05$], 8 days [$t(14) = 1.7$, $p > .05$], 16 days [$t(14) = .7$, $p > .05$].

Figure 2 shows the presses during extinction after 2, 4, 8, or 16 days of acquisition training. The single N-length group produced more responses during extinction than the multiple N-length group after each level of acquisition training. An analysis of variance (Training Day by Sequence) revealed a significant effect for sequence [$F(1,40) = 19.7$, $p < .01$] and Training Day by Sequence [$F(3,40) = 9.2$, $p < .01$]. The differences between the two sequences were significant at the end of 2 days of training [$t(10) = 2.4$, $p < .05$] and 4 days of training [$t(10) = 5.0$, $p < .01$]. Differences at 8 and 16 days were not significant [$t(10) = 1.6$, $p > .05$, and $t(10) = 1.5$, $p > .05$, respectively].

Because the results obtained from the extended training groups (the multiple N-length groups were less resistant to extinction than the single N-length groups) in this free-operant investigation were opposite to those predicted by Capaldi's sequential response hypothesis, it was decided to determine if a discrete trial box situation would produce results that were similar to Capaldi's runway situation or to the present free-operant situation. Experiment 3 was performed to determine if the present results were attributable to the instrumental operant distinction (presence or absence of an intertrial

Fig. 3. Resistance to extinction for discrete trial leverpress and free operant groups.

interval) or if the results were specific to the apparatus (an operant chamber). That is, since the present procedure differed from Capaldi's procedure in at least two important ways (operant vs instrumental and runway vs lever chamber), the effects of a discrete trial leverpress situation were compared with those of a free-operant leverpress situation to determine if the intertrial interval was a determinant of the disparate results.

EXPERIMENT 3

Subjects

The Ss were 24 naive female rats from the University of New Mexico colony. They were kept under the maintenance schedule described in Experiment 1.

Apparatus

The lever in each of the chambers was replaced by a lever that was capable of extending and retracting (Grisham, Wolach, & Ferraro, 1969). The new lever required 10 g of force and retracted and extended according to requisite programming contingencies (75 msec were required for retraction and 150 msec were required for extension). The lever had the same physical appearance as the lever used in the first two experiments. The apparatus (with the exception of the lever) was the same apparatus used in the two preceding experiments.

Procedure

The Ss were first pretrained with the rectangular lever described in Experiment 1. The next day the procedure was duplicated for 50 additional reinforcements with a smaller lever (.63 cm diam x 2.54 cm in length).

The Ss were assigned randomly to four experimental groups. Two of the groups experienced free-operant training conditions. The other two groups experienced a discrete trial leverpressing situation. The lever (.63 cm diam x 2.54 cm in length) retracted from the chamber after it was released. Fifteen seconds elapsed

before the lever returned to the chamber. The sequences with N-lengths of 6 or 2, 4, and 6 were used in this study. One discrete-trial group and one free-operant group experienced the single N-length sequence. The two other groups experienced the multiple N-length sequence. The Ss went through their sequence four times on a given day. All Ss received 4 days of acquisition training. Four 14-min extinction sessions followed on the next 4 days. The Ss that experienced free operant acquisition also experienced free-operant extinction. If a S experienced the discrete-trial procedure during acquisition, it experienced the discrete-trial procedure during extinction; i.e., the lever retracted for 15 sec after every press in extinction.

Results

The two free-operant groups had similar response rates at the end of acquisition [$t(10) = .7$, $p > .05$]. The two discrete-trial groups also showed similar response rates at the end of acquisition [$t(10) = .6$, $p > .05$].

Figure 3 shows the resistance to extinction for the four groups. The two free-operant groups were not significantly different in resistance to extinction [$t(10) = 1.8$, $p > .05$]. The results obtained from the free-operant groups replicated those obtained from the two groups in Experiment 2 (8 days of training) that received the same number of training trials.

The multiple N-length discrete-trial group displayed greater resistance to extinction than the single N-length group [$t(10) = 3.7$, $p < .01$]. The discrete trial lever chamber results parallel Capaldi's discrete-trial runway findings.

DISCUSSION

Experiment 1 was an attempt to replicate Capaldi's (1964) study in the free-operant situation. The Ss experiencing 192 and 384 acquisition trials performed as Capaldi's theory would predict. The single N-length Ss were more resistant to extinction after 192 trials (a relatively small number of trials in the free-operant situation). When Ss experienced additional training (384 trials), they showed the predicted increase in resistance to extinction for the multiple N-length group. After 768 trials, however, this difference could no longer be observed. The results suggested that Capaldi's theory could not predict resistance to extinction after extended training. The data seemed plausible, since Capaldi's runway study had not employed a group with nearly as many training trials as the present extended training group.

Experiment 2 used sequences that were more nearly equated in terms of transitions. The Ss in both groups

received about the same number of presentations of a given kind of transition relative to the three other kinds of transitions. In order to more nearly equate the two experimental groups it was necessary to employ more R-R and N-N transitions relative to R-N and N-R transitions in Experiment 2. Since Ss at all training levels showed greater resistance to extinction if they were trained on the single N-length sequence, Experiment 2 suggests Capaldi's sequential response theory cannot predict resistance to extinction in the free-operant situation.

The third experiment was performed to determine if the theory Capaldi had developed from discrete trial runway data could account for discrete trial leverpressing data or if it could predict extinction only in the runway situation. The study supported Capaldi's position in the discrete trial leverpressing situation, i.e., the multiple N-length Ss showed greater resistance to extinction than the single N-length Ss after a good deal of acquisition training (768 trials).

Data from the present study support the contention that the operant vs instrumental (discrete trial) distinction represents more than a procedural difference. Studies that manipulate the intertrial interval (making it longer or shorter) or vary the percentage of free operant and discrete trial leverpresses may help to explain the disparities in the operant and instrumental literature. Further information about sequenced reinforcement can be obtained with a two-way runway situation that can eliminate an intertrial interval outside of the runway (Wolach, Coutts, & Adelman, 1970). Such a situation is more like a discrete-trial lever chamber situation than conventional one-way runway situations.

REFERENCES

- ANDERSON, N. H. Comparison of different populations: Resistance to extinction and transfer. *Psychological Review*, 1963, 70, 162-179.
- CAPALDI, E. J. Effect of N-length, number of different N-lengths, and number of reinforcements on resistance to extinction. *Journal of Experimental Psychology*, 1964, 68, 230-239.
- CAPALDI, E. J. A sequential hypothesis of instrumental learning. In K. W. Spence and J. T. Spence (Eds.), *Psychology of learning and motivation*. Vol. 1. New York: Academic Press, 1967.
- GRISHAM, M. G., WOLACH, A. H., & FERRARO, D. P. An inexpensive retraction mechanism. *Behavioral Research Methods & Instrumentation*, 1969, 1, 233.
- SCHOENFELD, W. N. On the difference in resistance to extinction following regular and periodic reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 259-261.
- WOLACH, A. H., COUTTS, M., & ADERMAN, M. Sequenced reinforcement in a two-way runway situation. *Psychonomic Science*, 1970, 20, 267-269.