Increased resistance to extinction following partial reinforcement: A function of N-length or percentage of reinforcement?*†

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Rats were trained in a runway, with a 15-min ITI, in a 2 by 2 factorial design with two values of percentage of reinforcement (44.8% and 57.1%) and two values of N-length (long and short). There was also an appended CRF group. The short N-length groups had 100 N-R transitions, and the long N-length groups had 60 N-R transitions. Each N-length received a minimum of 10 reinforced occurrences. The low percentage Ss were most resistant to extinction, the high percentage Ss next most, and the CRF Ss least resistant. There was no N-length effect and no interaction.

A number of hypotheses attempt to explain the partial reinforcement effect (PRE) of increased resistance to extinction (Rn) following partial reinforcement (PRF). These hypotheses rely on variables that can be classified as either sequential or nonsequential. Some of the major nonsequential (or intratrial) variables that have been investigated are percentage of reinforcement, number of reinforced (R) trials, and number of nonreinforced (N) trials (Lewis, 1960). Sequential (or intertrial) variables involve transitions such as those from N to R trials and variations in the length and number of different lengths of run of consecutive N and R trials. Capaldi's (1964, 1966) stimulus aftereffects (SAE) hypothesis maintains that N-R transitions are necessary to obtain a PRE and, further, that Rn increases as a function of increases in the values of the sequential variables: N-length (successive N trials without an interposed R trial), number of different N-lengths, and number of reinforcements of each N-length.

Since manipulation of nonsequential variables usually will also affect sequential variables such as N-length and the number of N-R transitions, the sequential variables may be responsible for the magnitude of the PRE when percentage of reward is varied. Capaldi (e.g., Capaldi, 1964; Capaldi, Hart, & Stanley, 1963; Capaldi & Kassover, 1970) has manipulated N-length and percentage of reward independently. He found that Rn varies with changes in

N-length when percent of reinforcement is held constant but that Rn does not vary with variations in percent of reinforcement when N-length is held constant. Kotesky (1969) investigated the role of N-R transitions and reported that although the presence of some N-R transitions was necessary, percentage of reinforcement determined the magnitude of the PRE. Kotesky's experiment was a 2 by 2 factorial design, with 22 vs 13 N-R transitions, 46.8% vs 59.8% reinforcement, and an appended continuous reinforcement (CRF) group. He found a PRE and also found that the low percent reward group showed the greatest Rn, but there was no N-R transition effect. However, the design was such that N-length was also varied, with the 22 N-R groups receiving short N-lengths and the 13 N-R groups receiving long N-lengths. The confounding of these sequential variables is a shortcoming in Kotesky's reinforcement schedules, and his conclusions are, therefore, limited. Capaldi's (1966) model assumes that the instrumental response is conditioned to each value of N-length and that habit strength increases with each reinforcement of a particular N-length to some asymptote. The longest N-length in Kotesky's study was two (N_2) for one of the low percentage reinforcement groups and five (N_5) for the other low percentage group, but 18 occurrences of N_2 were reinforced, while N_5 was reinforced only twice; habit strength was certainly below asymptote for N_5 . Thus, at least for longer N-lengths, the Ss received abbreviated training. A similar situation obtained with the two high percentage groups.

If groups trained on the same schedules as Kotesky's were given extended training and it could be assumed that habit strength for all

N-lengths was asymptotic, the SAE hypothesis would predict certain reversals in their relative Rn (Capaldi, 1966). Specifically, the groups receiving the long N-lengths would be more resistant to extinction than the groups for which the N-lengths were short. Alternatively, predictions based on theories involving nonsequential variables would be essentially the same whether extended or abbreviated training was used. Moreover, the latter predictions would be in alignment with the results obtained by Kotesky (1969).

Capaldi (1964) obtained results indicating that for rats in comparable situations, some 10 reinforced trials are sufficient to achieve asymptotic habit strength for a particular N-length value. (A growth factor, $F = .352$, was computed for the present CRF group, indicating that response strength became asymptotic following eight reinforcements.) Since it is assumed that additional reinforcements do not serve to increase habit strength past asymptote (Hull, 1943), the present study replicated the Kotesky (1969) experiment using extended training (i.e., a sufficient number of trials to provide at least 10 reinforced occurrences of each N-length). Thus, it was possible to separate and assess the relative importance of percentage of reinforcement and N-length in determining the magnitude of the PRE.

DESIGN

The design, essentially identical to that used by Kotesky (1969), was a 2 by 2 factorial, with two values of the number of N-R transitions (100 and 60) and two values of percentage of reinforcement (44.8% and 57.1%). There was an appended CRF group. N-length was also varied with the 100 N-R transition groups each receiving N-lengths of 1 and 2 (short N-lengths) and the 60 N-R transition groups receiving N-lengths of 1, 2, 3, and 4 or 1, 2, 3, 4, and 5 (long N-lengths). The number of N-R transitions exceeded the number necessary to produce asymptotic habit strength for each N-length, and Capaldi's (1966) model states that under such conditions, N-R transitions will have no differential effect. The present study, therefore, focused primarily on the effect of percentage of reward vs that of N-length.

The five groups were designated as 44S (44.8%, short N-length), 44L (44.8%, long N-length), 57S (57.1%, short N-length), 57L (57.1%, long N-length), and CRF.

SUBJECTS

Thirty naive male albino rats of the Sprague-Dawley strain served as Ss. Six Ss were assigned randomly to each of

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TABLE 1
Daily Acquisition Schedules of Reinforcement and Mean Trials
to Criterion for each of the Experimental Groups
44.8 Percent Reinforcement 57.1 Percent Reinforcement

	Group 44S	Group 44L	Group 57S	Group 57L
Schedule	Short N-length	Long N-length	Short N-length	Long N-length
A	RNRRNR	RRNNNR	RNRRNR	RRNNNR
B	NNRRNR	NRNNNR	NNRRNR	NRNNNR
C	RNRRNRNR	RRNNNRNR	RNRRNRNR	RRNNNRNR
D	NNRRNRNR	NRNNNRNR	NNRRNRNR	NRNNNRNR
Mean number of trials to extinction criterion	87.33	75.66	55.5	61.83

the five groups. The Ss were approximately 120 days old at the start of training.

APPARATUS

A 242.88-cm (8-ft) straight runway, fully described in Kotesky & Stetner (1968), was used. The first and last 30.36 cm (1 ft) constituted start- and goalboxes, which were separated from the runway by guillotine doors. Photocells, located 5.06 cm (2 in.) past the startbox door and 5.06 cm (2 in.) inside the goalbox, controlled two clocks which recorded start (2 in.) and run (7 ft) latencies. The apparatus was modified in that a blower was placed in the end of the goalbox to evacuate pheromones.

PROCEDURE

The Ss were food deprived and maintained on a 10 g/day feeding schedule during the experiment. They were handled each day during the pretraining period, which began 2 weeks prior to the first day of

acquisition, and were fed immediately after being handled. One day prior to the beginning of acquisition, each S was placed in the goalbox and received four Noyes pellets. On the first 2 days of acquisition, each S received three reinforced trials. They were then put on the schedules of reinforcement shown in Table 1, which are identical to those used by Kotesky (1969). The schedules were used, one per day, in the order A, B, C, D, A . . . , with each schedule occurring 10 times. The Ss were run in squads of 15 Ss each (3 animals from each group per squad) and were placed in their home cages for a 15-min interval between trials. There was a total of 326 acquisition trials carried out over 42 days. Four 45-mg Noyes pellets were given on R trials, and on N trials, S was confined to a goalbox for approximately 10 sec. The balance of the 10 g of food was given 15 min after the last trial of the day.

Fig. 1. Number of Ss per group having reached the extinction criterion as a function of trials.

Extinction began on Day 43, with each S receiving seven N trials per day. All Ss received a minimum of 10 days of extinction trials. Each S received additional extinction trials until it reached the extinction criterion of two consecutive trials with a running time greater than 60 sec.

RESULTS

All start and run latencies were transformed to logarithms ($\log_{10} 100X$). There were no differences among the five groups at the end of acquisition ($F < 1$). There were no significant effects in the analysis of the extinction latency data, although the percentage effect trend for the run times was in the same direction as the trials to criterion results. Perhaps with a larger number of Ss these differences would have attained significance. Since Kotesky (1969) also recorded, but did not report, latencies, it appears that in the present situation, the trials to criterion measure is the more sensitive. Therefore, the main emphasis is on the trials to extinction criterion data. Table 1 also shows the mean number of extinction trials to reach the criterion of two consecutive trials over 60 sec. The control group (CRF) extinguished in 40.83 trials. The performance of all groups in extinction is shown in Fig. 1 in terms of the number of animals having reached the extinction criterion. A one-way analysis of variance of the number of trials to criterion for the five groups yielded $F = 3.82$ ($p < .05$, $df = 4,25$). The four PRF groups were then compared with the CRF group ($F = 7.03$, $p < .05$, $df = 1,25$), which indicated that there was a PRE. A 2 by 2 factorial analysis was then computed for the PRF groups. The F for the percentage factor was significant ($F = 6.869$, $df = 1,25$, $p < .05$), but the F value for N-length was not ($F < 1$); nor was there a significant interaction ($F < 1$). Since Groups 57S and 57L revealed the least Rn among the PRF groups, for additional information they were compared with the CRF group to determine if they were more resistant than the CRF group. The comparison yielded $F = 9.195$ ($df = 1,25$, $p < .01$). In fact, a t test indicated that Group 57S, the least resistant of the PRF groups, was more resistant than Group CRF ($t = 3.146$, $df = 10$, $p < .05$, two-tailed test). Therefore, all of the experimental groups exhibited the PRE, with the low percentage groups being most resistant, the high percentage groups next most, and the CRF group least. There was no evidence of any N-length effect. In fact, the mean number of trials to extinction criterion was greater for Group 44S (which never had a

N-length greater than N_2), even though N_5 for Group 44L had 10 reinforced occurrences.

DISCUSSION

Based on the trials to extinction criterion data, the PRF groups were more resistant to extinction than the CRF group, increased Rn following PRF was inversely related to percentage of reinforcement during acquisition, Rn was unaffected by N-length, and there was no interaction. Essentially, these results are the same as those of Kotesky (1969), even though habit strength should have been asymptotic for all values of N-length. These data, therefore, appear inconsistent with predictions based on Capaldi's sequential aftereffects hypothesis. Specifically, it was not found that the groups with the larger values of N-length were more resistant to extinction.

Gonzalez & Bitterman (1964) reported Rn to be a function of N-length but not significantly affected by percentage of reinforcement. They suggested that the inverse relation between Rn and percentage of reinforcement found previously may have been due to the usual inverse relation between N-length and percentage of reinforcement. That is, low percentage schedules usually have high values of N-length embedded in them. However, that situation did not occur in the present study. A possible reason for the difference between the present study and the findings of Capaldi (1964) and Gonzalez & Bitterman (1964) could be, as suggested by Kotesky & Stetner (1968), differences in the length of the intertrial intervals (ITIs) used. This appears to be a consistent difference between the studies that report sequential effects and those that do not. For example, the present study and the studies by Kotesky employed ITIs of 15 min or more; the studies by Gonzalez & Bitterman (1964) and those by Capaldi employed ITIs of 30 sec or less. Although Capaldi & Spivey (1964) found sequential effects to be operative following a 24-h ITI, Surridge & Amsel (1966) offered evidence suggesting that Rn may be regulated by sequential effects only under conditions of massed trials. Gonzalez & Bitterman (1969) reported

a study using a 1-h rather than a 15-sec ITI, but otherwise the study was identical to Capaldi's (1964). The N-length effect reported by Capaldi was not found. Capaldi & Kassoover (1970) obtained apparent evidence for sequential effects following a 20-min ITI and concluded that such effects, do not depend upon an extreme massing of trials. However, Capaldi's reward schedules were biased in favor of the N-length variables. Schedules designed to test the frustration hypothesis, unlike those designed to control N-length, did not end with an R trial, thereby possibly not permitting generalized anticipatory frustration to become conditioned to the response. The data from the present study, which used a 15-min ITI and in which all schedules ended with an R trial, do not support Capaldi's sequential effects hypothesis.

These data can also be interpreted in terms of responsivity (Capaldi, 1967). Responsivity refers to the extent to which stimuli, including aftereffects from previous R and N trials, are operative on any given trial. When responsivity is high, only aftereffects occasioned on Trial X are operative on Trial X + 1, whereas, when responsivity is low, aftereffects occasioned on earlier trials may be operative on any given trial. While Capaldi (1967) has assumed responsivity to be high whether the ITI is short or long, the evidence for the effectiveness of sequential variables following relatively long ITIs is inconclusive; many studies fail to find N-length to be crucial when a long ITI has been used. In other words, if responsivity is inversely related to length of ITI, the effectiveness of sequential variables would be expected to vary along with variations in the length of the ITI used. An assumption of low responsivity with long ITIs could then account for the data of the present experiment as well as much of the discrepant evidence concerning the SAE and frustration hypotheses. This assumption of low responsivity with long ITIs essentially recasts the problem in terms of memory processes. That is, with a longer ITI, the aftereffects of trials prior to the immediately preceding one may be present on the current trial. Such

proactive interference has been shown to increase with increases in the retention interval in human memory studies (Greenberg & Underwood, 1950).

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