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Effects of percentage of reinforcement and number of reinforcements in S+ on discrimination learning in the runway

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Williams (1989) reported that discrimination learning and its reversal in the operant chamber are regulated by the number of reinforcements to the S+ alternative independently of reinforcement schedule, a finding Williams called the invariance effect. To determine whether there is an invariance effect in the runway, we trained four groups of rats on a successive brightness discrimination problem and its reversal. The experimental design was a factorial combination of two reinforcement schedules associated with S+ (partial reinforcement, PRF, vs. consistent reinforcement, CRF) and the number of trials per day to S+ (five vs. seven). The design provided one PRF group and one CRF group given the same number of reinforcements to S+. It also provided for a comparison between two PRF groups given different percentages of reinforcement in S+, and for PRF and CRF groups given the same number of trials in S+. PRF impaired both original discrimination learning and reversal learning whether PRF and CRF groups were equated for number of trials or for number of reinforcements, and learning was not affected by the percentage of reinforcement difference between the two PRF groups. Thus, no invariance effect was obtained.

Recently, Williams (1989) investigated the effects of partial reinforcement (PRF) to S+ in instrumental discrimination learning and reported that, regardless of the percentage of reinforcement associated with S+, a constant number of reinforcements to S+ was required for subjects to learn the discrimination or its reversal. In other words, PRF did not impair discrimination learning relative to a number-of-rewards consistent reinforcement (CRF) control condition. According to Williams, instrumental discrimination learning is an invariant function of the number of reinforced responses to S+ regardless of the percentage of reinforcement to S+, an outcome he labeled an invariance effect.

The invariance effect, if it exists, is important. First, it is inconsistent with learning theories (e.g., Capaldi, 1974; Rescorla & Wagner, 1972) that attribute responding to some additive combination of excitation and inhibition. This is so because nonreinforcements to the S+ should increase the inhibitory process incrementally, and the added inhibition would then have to be compensated for by additional reinforcements administered to the PRF group in order for the PRF and CRF groups to respond alike. Second, the invariance effect is inconsistent with theories that suggest that performance is regulated by internal cues produced by goal events such as reinforcement and nonreinforcement (see, e.g., Amsel, 1958; Capaldi, 1966). We have shown these cues to be an important source of stimulus control in instrumental discrimination learning (e.g., Capaldi, Berg, & Morris, 1975; Capaldi, Miller, Alptekin, Barry, & Haggbloom, 1991; Haggbloom, 1978).

According to Williams, the invariance effect is widespread and consistent with available discrimination learning data. On the other hand, the results of a number of runway discrimination learning investigations appear to be inconsistent with an invariance effect (Capaldi et al., 1975; Capaldi et al., 1991; Grosslight & Radlow, 1956, 1957; Haggbloom, 1978, 1980a, 1980b, 1980c, Experiment 1, 1981; Haggbloom & Tillman, 1980, Experiment 2). However, those investigations were not specifically designed to investigate the invariance effect and so did not include CRF control groups equated with PRF groups on number of reinforcements in S+.

The purpose of our present experiment was to specifically investigate whether or not PRF in S+ retards discrimination learning in the runway relative to a number-of-rewards CRF control group. We trained four groups of rats according to a 2×2 factorial design with S+ reward schedule (PRF vs. CRF) as one variable and number of trials (five vs. seven) on S+ days of training as the other variable. S+ and S− trials were administered on separate (and alternate) days of training. This procedure ensures that manipulations of PRF in S+ are not con-

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founded with sequential variables involving transitions from nonrewarded (N) trials in S− to rewarded (R) trials in S+ (see Haggbloom, 1980b). The experimental design provides for one PRF group and one CRF group (Groups PRF-7 and CRF-5) that are equated on number of rewards, both groups receiving five R trials on each S+ day. It also provides conventional number-of-trials controls for both PRF groups, and it allows for a comparison between PRF groups that differ in percentage of S+ reward. A reversal learning phase, administered according to the same 2×2 factorial design, followed training on the original discrimination.

METHOD

Subjects

The subjects were 16 male rats selected randomly from the colony of Holtzman-derived stock maintained at Arkansas State University. The rats were approximately 120 days old at the start of experimental training.

Apparatus

The apparatus consisted of two parallel straight alleys 105 cm long by 9 cm high and wide. The walls and floor of one alley were painted white, and the walls and floor of the other alley were painted black. The last 25 cm of each alley constituted a goalbox that was separated from the rest of the alley by a manually operated guillotine door. The doors and goalboxes were painted in the same color as that of the alley in which they were located. Each goalbox contained an unpainted wooden goal cup. A gray startbox, 9 cm high and wide by 25 cm long, could be aligned to permit entry into one alley or the other. The startbox had a gray, manually operated guillotine door. A .01-sec stop clock recorded running time over a 100-cm distance from the opening of the startbox door to a point 5 cm from the end of the goalbox.

Procedure

The rats were housed in individual cages with access to water at all times. Two weeks prior to the start of training, and continuing throughout the experiment, the rats were placed on a food-deprivation regimen of 15 g of food per day consisting of lab chow or lab chow and .045-g food pellets received during training. On Days 12-14 of deprivation, the rats were handled in squads of 2 for 2 min per squad and then were fed eight .045-g food pellets from a small dish in the home cage. Four rats were randomly assigned to each of four groups defined by a 2×2 factorial combination of S+ reward schedule (PRF vs. CRF) and number of trials received on S+ days (five vs. seven): Groups PRF-5, PRF-7, CRF-5, and CRF-7. In original learning, 6 days of training in the S+ alley (Days 1, 3, 5, 7, 9, and 11) were alternated with 6 days of training in the S− alley (Days 2, 4, 6, 8, 10, and 12). Over successive S+ days, Group PRF-5 received the PRF schedules RNRNR, NRRNR, RRNNR, NRNRR, RNRNR, and NRRNR; Group PRF-7 received the same schedules with two R trials added to the end of each schedule. Groups CRF-5 and CRF-7 received five and seven R trials, respectively, on each S+ day. All groups received four consecutive N trials on each S− day of training. In reversal learning, the PRF schedules on successive, odd-numbered days of training in the reversal S+ alley were RRNNR, NRNRR, RNRNR, NRRNR, RNRNR, and NRRNR. All other procedures in reversal learning were the same as those in original learning.

In both training phases, subjects were run in squads of 4 that contained 1 subject from each group. The order of running subjects within a squad was varied randomly across days, but the order of successive squads was held constant. In original discrimination learning, S+ was the white alley and S− was the black alley for one half of the subjects in each group. The counterbalancing arrangement obtained for the remaining subjects in each group. Rats received eight .045-g food pellets on all R trials and were confined to the unbaited goalbox for 20 sec on N trials. At the beginning of each trial, a rat was placed in the startbox and the startbox door was opened approximately 3 sec later. A maximum time of 60 sec was allowed for the rat to traverse the runway, after which it was placed in the goalbox.

RESULTS

All analyses were performed on difference scores obtained for each rat by subtracting running time on S− trials from running time on *rewarded* S+ trials, in the following manner. A subject's time on S− Trial 1 was subtracted from that subject's time on the first R trial in S+ (S+ Trial 1 for all groups); time on S− Trial 2 was subtracted from time on the second R trial in S+ (S+ Trial 2 for Groups CRF-5 and CRF-7 and S+ Trial 3 for Groups PRF-5 and PRF-7. Calculated in this way, differences between S+ and S− running times measure discrimination behavior after equal numbers of rewarded S+ trials for the four groups. These data are presented in the top panels of Figure 1 (original learning) and Figure 2 (reversal learning) in blocks of three reinforced trials for each group. Each group received a total of 24 N trials in S− in both original learning and reversal learning. Groups PRF-5, PRF-7, CRF-5, and CRF-7 received totals of 18, 30, 30, and 42 rewarded S+ trials, respectively, in both discrimination phases. Thus, difference scores could be calculated only over 18 trials in both phases for Group PRF-5, using all 18 rewarded S+ trials and the first 18 S− trials. For the other three groups, difference scores were based on only the first 24 rewarded S+ trials and all 24 S− trials. For purposes of comparison with what

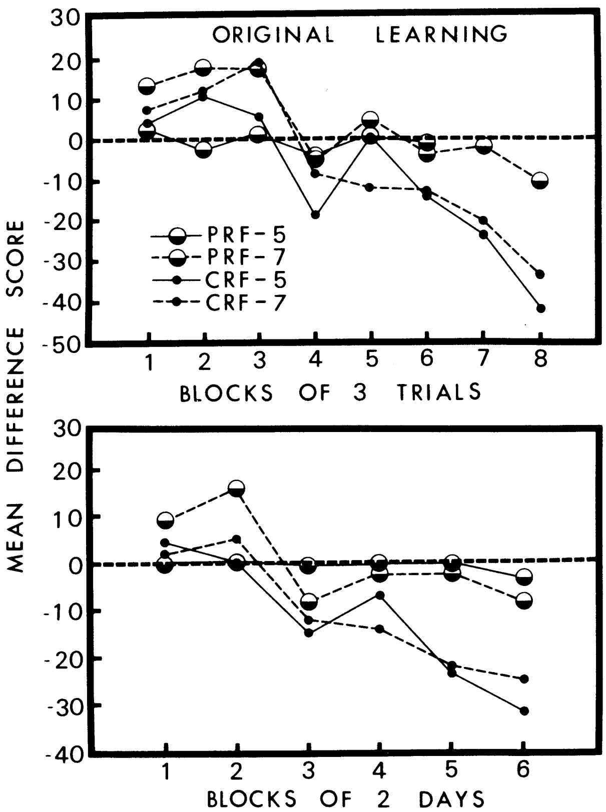

Figure 1. Difference scores for each of the four groups in original learning following equal numbers of reinforced S+ trials (top panel) and based on all trials (bottom panel).

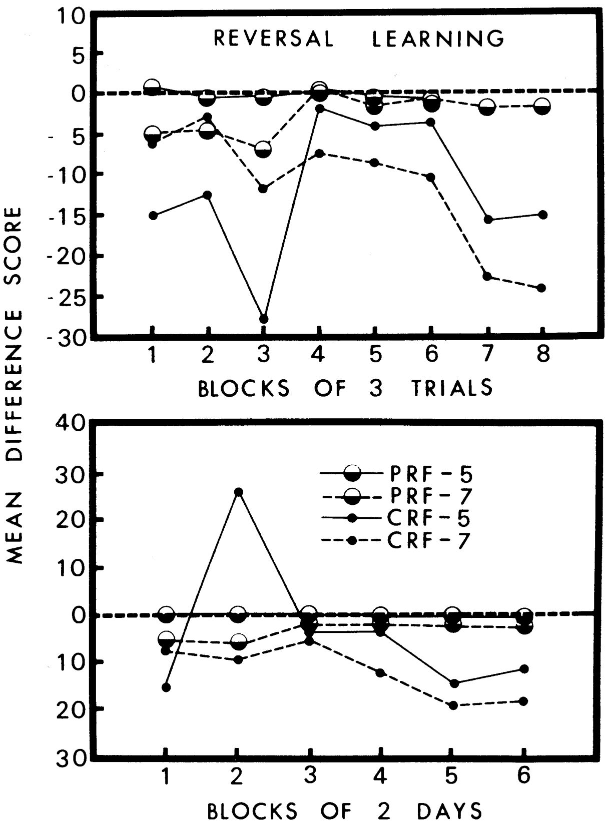

Figure 2. Difference scores for each of the four groups in reversal learning following equal numbers of reinforced S+ trials (top panel) and based on all trials (bottom panel).

might be considered a more conventional method of reporting this type of discrimination learning data, the bottom panels in each figure present difference scores obtained by subtracting the mean daily S− running time from the mean daily S+ running time for each successive pair of S+ and S− days.

As can be seen in Figures 1 and 2, the relationships among the four groups were essentially the same for both data presentation formats. Therefore, we report statistical analyses only for difference scores based on equal numbers of reinforced S+ trials among the four groups.

Figures 1 and 2 show that, in both original learning and reversal learning, PRF retarded discrimination learning relative to CRF independently of the number of reinforced S+ trials. Moreover, discrimination learning was equally impaired in Groups PRF-5 and PRF-7 relative to both Groups CRF-5 and CRF-7, which in turn did not differ from each other.

A 2 (reward schedule) × 2 (number of trials) × 3 (blocks) analysis of variance (ANOVA) was applied to difference scores over Trial Blocks 4-6. The ANOVA showed that the mean difference score for CRF subjects ($\overline{X} = -33.08$) was significantly greater than that for PRF subjects ($\overline{X} = -1.74$) [$F(1,11) = 5.03, p < .05$]. There were no differences due to the number of trials variable ($F < 1$), nor was there a reward schedule × number of trials interaction ($F < 1$). There were no significant effects involving the blocks variable.

An identical ANOVA applied to Reversal Learning Trial Blocks 4-6 showed that in reversal learning, as in original learning, the mean difference score for CRF subjects ($\overline{X} = -19.33$) was significantly greater than that for PRF subjects ($\overline{X} = -0.47$) [$F(1,11) = 10.30, p < .01$]. Again, there were no differences due to number of trials ($F < 1$), and there was no reward schedule × number of trials interaction ($F < 1$). There were no significant effects involving the blocks variable.

DISCUSSION

Our experiment shows that instrumental discrimination learning in the runway is impaired by PRF for responding to the S+, relative to CRF, whether PRF and CRF subjects receive the same number of S+ trials or the same number of S+ rewards. Moreover, this effect is apparent even when PRF and CRF subjects are compared after equal numbers of reinforced S+ trials. Thus, instrumental discrimination learning, in the runway at least, is impaired by PRF independently of number of reinforced S+ trials—that is, there is no invariance effect.

It is not immediately obvious why an invariance effect would occur in some situations, but not in others, and any analysis of the problem is complicated by the many differences in experimental procedures between the operant chamber and runway situations that have been employed. Our approach to this problem was to ask whether learning theories that posit increments to an inhibitory process on nonreinforced trials (e.g., Capaldi, 1974; Rescorla & Wagner, 1972)—models supposedly incompatible with the invariance effect—might nonetheless predict that effect under some conditions. We think that they would, and that one such condition is the use of a relatively small magnitude of reinforcement.

According to Capaldi (1974), for example, inhibition develops on trials on which the expected reinforcement exceeds the obtained reinforcement and is an increasing function of the size of that disparity—a disparity that would be quite small under conditions of small reward delivered on a PRF schedule. For different reasons, the Rescorla-Wagner model delivers the same prediction. Consistent with this analysis, the invariance effects reported to date were obtained with what would appear to be quite small rewards: access to grain for 3 sec (Eckerman, 1969; Williams, 1981) or 3.5 sec (Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980), and .01 cc of corn oil (Williams, 1989).

One of the reasons why PRF has generated so much experimental and theoretical interest is that its effects are often counterintuitive. One of the lessons of this work has been that the identification of stimulus control in instrumental learning requires attention to the possible control exercised by internal reinforcement-related stimuli. As Neely and Wagner (1974) have noted:

> Additional complexities are introduced into any theoretical analysis when one assumes that schedule-generated stimuli must be taken into account along with nominal cues. Such an assumption has been extremely useful, however, in understanding the effects of reward manipulations in instrumental-learning situations (e.g., Amsel, 1962; Capaldi, 1966; Wagner, 1961). (p. 163)

Our present results agree with those of earlier experiments showing that in discrimination learning, as in nondiscrimination learning, the behavioral effects of PRF depend on the sequence of R and N trials and are largely independent of such nonsequential variables as number of rewards and percentage of reward.

According to the sequential view (Capaldi, 1966, 1967), R and N occasion distinctive internal stimuli (e.g., memories), denoted here as S^R and S^N, respectively. Many of the behavioral effects of variations in reinforcement conditions in instrumental learning, including, most notably, effects of PRF, are mediated by the behavioral control exercised by S^R and S^N.

In instrumental discrimination learning, the rate of learning is influenced both by the relative capacities of the nominal S+ and S− cues to signal reinforcement and by the capacities of S^R and S^N to signal reinforcement (e.g., Capaldi et al., 1975; Capaldi et al., 1991; Haggbloom, 1978, 1980b; Haggbloom & Tillman, 1980). As with any other cues, the behavioral control exercised by S^R and S^N is determined by their history of reinforcement. For example, if early in discrimination training, a nonrewarded trial either in S+ or in S− is followed by a rewarded trial in S+, S^N as well as the S+ cue would acquire an increased capacity to signal reinforcement. Thus, if S^N, which has acquired the capacity to signal reinforcement, were subsequently retrieved in the S− alternative, it would tend to promote vigorous responding even if the capacity of the S− cue to elicit responding is weak. As is perhaps clear, the behavioral control exercised by S^R and S^N is regulated by the sequence of occurrence of reinforced and nonreinforced trials.

We have previously shown S^R and S^N to be important sources of stimulus control mediating the effects of PRF in instrumental discrimination learning. Yet another reason why small rewards might contribute to an invariance effect is the fact that behavioral control by S^N is substantially reduced when responding is conditioned to S^N by small rewards. Thus, the partial reinforcement extinction effect is smaller under conditions of small reward (e.g., Wagner, 1961), and the impairment of discrimination learning produced by PRF is reduced by small rewards (Haggbloom, 1980c).

In conclusion, we suggest that the invariance effect is neither widespread nor necessarily incompatible with existing theoretical formulations.

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