Inhibitory associations between S and R in extinction

ROBERT A. RESCORLA
University of Pennsylvania, Philadelphia, Pennsylvania

The associative changes that occur in extinction were investigated in four instrumental learning experiments. Experiment 1 used transfer based on a shared outcome to detect the continued presence of response-outcome (R-O) and stimulus-outcome (S-O) associations after a response had been nonreinforced in the presence of its controlling stimulus. Experiments 2-4 found that extinction resulted in the learning not to make a particular response in the presence of a particular stimulus, despite those continued R-O and S-O associations. These results suggest that extinction may superimpose upon those original outcome associations an inhibitory S-R association.

Modern analyses of the learning supporting instrumental behavior point to the presence of various associations. There is evidence for the development of pairwise associations between the instrumental response (R) and the earned outcome (O), as well as between the discriminative stimulus (S) and the outcome, and perhaps between S and R. In addition, some results indicate the development of more hierarchical structures, such as an association between S and the R-O relation (see Rescorla, 1991b, for one recent summary). These various associations work together, in ways that are not yet fully understood, to produce instrumental performance.

Much of the evidence for associations involving O comes from the use of two techniques: devaluation and transfer. In a typical devaluation paradigm, an instrumental training procedure offers the opportunity for the development of an association between R and O, and then that O is devalued by being paired with a toxin. Subsequent tests show that the response that previously earned an outcome is specifically depressed as a result of that outcome's devaluation (see, e.g., Colwill & Rescorla, 1985). In a typical transfer paradigm, both S-O and R-O associations are identified by the ability of an S to transfer to a novel R on the basis of the R's having earned a particular O and the S's having signaled the availability of that same O for another R (see, e.g., Colwill & Rescorla, 1988). That is, a response is augmented more by a stimulus that signals the same O than by one that signals a different O.

The successful identification of these various associations in initial learning naturally raises the question of how they fare when the contingencies change. Of particular interest is the effect that extinction might have on these learned associations. Recent work from this laboratory suggests that both the R-O and the S-O associations survive various extinction operations. An originally learned R-O association seems little affected by the omission of O, the making of O random with regard to the response, or the replacing of O by an alternative outcome (e.g., Rescorla, 1991a; 1992c). Although some of these operations produce substantial deterioration in responding, they apparently leave the R-O association relatively intact. Even after extensive extinction, the R-O association continues to be detectable (perhaps at full strength) by both the devaluation and the transfer procedures. Similarly, operations of this sort apparently have little effect on the S-O association developed during original training, as detected with the transfer procedure (Rescorla, 1992a).

The continued strength of the R-O and S-O associations, despite the institution of an extinction contingency, suggests that changes in other associations might be responsible for at least some of the observed loss in performance. One possibility, suggested by Colwill (1991), is that extinction induces an inhibitory association between S and R. Such an association might be superimposed in the course of extinction, leaving the original S-O and R-O associations intact, but preventing performance. Colwill has argued for development of such an association when S explicitly signals that R will be nonreinforced. She observed that such an S can continue to suppress its original R even when subsequent training allows it to augment another response based on an S-O association. Similarly, Rescorla (1992a) found that following extinction of R1 during its S, that S continued to transfer to other Rs, despite no longer being able to evoke its own R1.

The goal of the present experiments was to explore further the possibility that extinction is partly accomplished by the establishment of such an inhibitory association between S and R. Experiment 1 further documents the preservation of the R-O and S-O associations through extinction. It assesses for the same learning episode the impact of extinction on both the R-O and the S-O associations. Experiments 2-4 explore more directly the possibility of a modification of the S-R association.

All of the experiments used rat subjects in standard operant tasks in which responses such as leverpress and chainpull led to outcomes such as pellets and sucrose in the presence of various signals, such as a noise or light.

EXPERIMENT 1

Previous experiments have separately assessed the state of the R-O (e.g., Rescorla, 1991a) and the S-O (e.g., Rescorla, 1992b) associations after extinction. Each association was individually found to persist. The present experiment assessed for the same outcome in the same animal the state of both associations after extinction. The concurrent preservation of both associations from the same initial learning, despite extinction, would suggest the involvement of some outcome-independent decremental process.

The main features of the experimental design are illustrated in Figure 1. The rats were trained to make four different instrumental responses, each in the presence of one of four different stimuli. Initially, two different auditory stimuli, A1 and A2, signaled that two different responses (R1 and R2, leverpress or chainpull) would lead to unique outcomes (O1 or O2, pellet or liquid sucrose). In addition, two different visual stimuli, V1 and V2, signaled that two other responses (R3 and R4, nosepoke or handlepull) would lead to the same outcomes. Then the response (R1) trained with one of the auditory stimuli (A1) was extinguished. Naturally, the likelihood of R1 was expected to decline in the presence of A1. The issue of interest is the strength of the "extinguished" A1-O1 and R1-O1 associations relative to the strength of the "nonextinguished" A2-O2 and R2-O2 associations.

The strengths of those associations were assessed in the subsequent transfer tests. The first test superimposed the visual stimuli signaling the availability of different outcomes on the extinguished and nonextinguished responses. To the degree that the R1-O1 and R2-O2 associations are still intact, each response should be specifically elevated by a visual stimulus that signals its earned outcome. Thus, this test provides information about the state of the extinguished R1-O1 and the nonextinguished R2-O2 associations. The second test superimposed the extinguished and nonextinguished auditory stimuli on R3 and R4. To the degree that A1 and A2 still have their out-

come associations intact, they should augment the responses with which they share an outcome. Thus, this test provides information about the state of the extinguished A1-O1 and nonextinguished A2-O2 associations.

Method

Subjects and Apparatus

The subjects were 16 male Sprague-Dawley rats about 90 days old. They were housed in individual cages and maintained on a food-deprivation regime that kept them at 80% of their ad-lib body weights. They had free access to water in the home cage.

The apparatus consisted of eight operant chambers measuring 22.9×20.3×20.3 cm, similar to those used in previous reports (e.g., Colwill & Rescorla, 1985). The two end walls of each chamber were aluminum; the sidewalls and ceiling were clear Plexiglas. Each chamber had a recessed food magazine in the center of one end wall. Two small metal cups measuring 1.25 cm in diameter and 1.5 cm deep were sunk side by side in the floor of each food magazine. To the left of the magazine was a lever and to the right was a chain suspended from a microswitch mounted on the lid of the chamber. Located directly above the food magazine was a 2-cm opening, behind which was an aluminum plate that activated an attached microswitch when displaced by a nosepoke. Inserted under the grid floor, just to the right of the magazine aperture, was a flat metal rod, one end of which was bent back to form a handle. An upward pull on this handle operated a microswitch. Access to these manipulanda could be blocked by covering the lever with a metal shield, retracting the chain through a hole in the ceiling, covering the nosepoke opening with a jeweled lens, and removing the handle pull from under the grid floor. The floor of the chamber was composed of 0.48-cm stainless steel rods, spaced 1.9 cm apart. Each chamber was enclosed in a sound- and light-resistant shell. Mounted on the inside wall of this shell were speakers that permitted the presentation of a white noise (N) and an 1800-Hz tone (T), each measuring approximately 76 dB re 20 $\mu N/m^2$ against a background level of 62 dB. Also mounted on that wall was a 6-W bulb that could be illuminated to provide a light (L) stimulus during the otherwise dark session. Another 6-W light was mounted at grid level outside the rear wall of the chamber; this light could be flashed at a rate of 1/sec to provide a flashing (F) stimulus. The outside ceiling of the shell supported two solenoid-operated gravity feed valves that were connected via plastic tubing to the cups in the food magazine. One system permitted the presentation of .3 ml of an 8% sucrose solution; the other permitted the presentation of .3 ml of a 15% Polycose solution. Also attached to the food magazine was a dispenser containing 45-mg pellets (P. J. Noyes, Formula A).

Experimental events were controlled and recorded automatically by relays and microprocessors located in an adjoining room.

Procedure

Initial training. On the 1st day, the animals received two 20-min magazine training sessions, the first containing 20 pellet deliveries and the second containing 20 sucrose deliveries. Over the next 4 days, all animals were trained to make all four responses. Each training session allowed responding to earn 25 deliveries of the appropriate outcome on a continuous reinforcement schedule. Half the animals received one session in which leverpressing led to pellets and one in which chainpulling led to sucrose; for the other half of the animals, the contingencies were reversed. In an orthogonally arranged fashion, half the animals received one session in which the nosepoke response led to pellets and one in which the handlepull response led to sucrose; for the other half of the animals, the contingencies were reversed. Throughout this initial training, individual shaping was used if necessary for a particular R-O combination.

On each of the next 4 days, the animals received training of the four responses on a variable interval (VI) 60-sec schedule. On each

Discrimination		Extinction	Test of R–O	Test of S–O
A1: R1–O1	V1: R3–O1	A1: R1–	V1 V2 R1, R2	A1 A2 R3, R4
A2: R2–O2	V2: R4–O2			

Figure 1. Design of Experiment 1. Discrimination training was given with two auditory (A) and visual (V) stimuli, each signaling the reinforcement of a particular response (R) with a particular outcome (O). Following extinction of R1 in A1, two transfer tests were given. In one test, the R1–O and R2–O associations were assessed by the ability of a same-outcome visual stimulus to augment responding. In a second test, the A_1–O_1 and A_2–O_2 associations were assessed by their ability to augment same-outcome transfer responses.

day, the animals received two 20-min sessions, one with lever and one with chain or one with nosepoke and one with handlepull. On Days 1 and 4 of this procedure, lever and chain were trained; on Days 2 and 3, nosepoke and handlepull were trained. The R–O combinations were the same as those used during initial training.

Discrimination training. On each of the next 20 days, the animals received discrimination training sessions with various combinations of stimuli and responses. On each of the first 8 days, the animals received two sessions, each containing 16 presentations of a 30-sec stimulus. On 4 of those days, the noise was the stimulus in one session and the tone in the other; on the other 4 days, the stimuli were the light and flash. During these stimuli, responding resulted in reinforcements according to a VI 30-sec schedule. Treatments were counterbalanced so that for half the animals lever was present during noise and chain was present during tone; for the remaining animals, the manipulanda were interchanged. Similarly, for an orthogonally selected half of the animals, nosepoke was available during light and handlepull during the flash; for the remaining animals, the manipulanda were interchanged. In a manner counterbalanced with regard to previous treatments, half the animals in each condition received pellets as the earned outcome during one auditory stimulus and sucrose as the outcome during the other auditory stimulus. Similarly, half received pellets as the outcome during one visual stimulus and sucrose as the outcome during the other. The intertrial interval (ITI) was variable around means of 15, 30, and 60 sec for the first 3 days of training with each modality, respectively. Thereafter, the mean ITI was 90 sec. On the final 12 days of this treatment, each animal received four sessions per day, one with each stimulus, with the order balanced across days.

Extinction. On each of the next 6 days, the animals received extinction with one of the auditory stimuli and its response. Each session contained thirty-two 30-sec presentations of either N or T with the appropriate response continuously available. The ITI was variable around a mean of 90 sec. For half the animals, N was selected for extinction, and for half, T was selected; similarly, for half the animals, lever was the extinguished response, whereas for the other half, chain was the extinguished response.

Response retraining. On each of the next 2 days, the animals received two 20-min VI 60-sec retraining sessions. Lever was present during one of these sessions and chain was present during the other. The outcome earned was a 15% Polycose solution. The intention of this training was to make more similar the overall likelihood of previously extinguished and nonextinguished responses. The procedure of training with a third, otherwise irrelevant, outcome has previously been routinely used for this purpose because it has been shown not to have a strong impact on the originally trained R–O associations despite increasing response probability (Rescorla, 1991a).

On the next day, each animal received two 8-min extinction sessions, one with leverpressing and one with chainpulling. The intention of this procedure was to reduce overall rates of both responses, in order to allow the discriminative stimuli to elevate behavior on the subsequent test (see Colwill & Rescorla, 1988).

Test. On each of the next 3 days, the animals received two 8-min test sessions. Both sessions of the 1st test day contained four 30-sec presentations each of L and F, given in counterbalanced order with an ITI of 30 sec. Lever was present during the first session and chain during the second. The goal of this test was to evaluate the state of the extinguished and nonextinguished R–O associations for the lever and chain. The 2nd test day was the same, except that N and T were the stimuli and nosepoke and handlepull were the manipulanda. These sessions provided information on the extinguished and nonextinguished S–O associations for L and F. On the 3rd day, the two test sessions contained lever and chain, respectively. Each session involved four 30-sec presentations of each of the auditory stimuli. This session allowed verification of the suc-

cess of the original extinction manipulations. No outcomes were given during the test sessions.

Results and Discussion

Initial response training and discrimination learning proceeded smoothly. On the final day of discrimination training, the mean responses per minute were 9.3 and 15.4 during the auditory and visual stimuli, respectively. The mean response rates during the ITI were 1.9 and 3.5, respectively. Over the course of extinction, the mean responses per minute dropped to .49 and .36 during the stimulus and ITI, respectively, on the final day. With the introduction of Polycose reinforcement for the lever and chain, the mean responses per minute rose to 6.7 in the final training session, with no reliable differences between the extinguished and nonextinguished responses. By the final 2 min of the short pretest extinction session, the mean number of responses per minute was 3.9.

Transfer to treated responses. The results of the first transfer test session, when the Light and Flash were presented while the animal had the lever or chain available, are shown in Figure 2. That figure displays the rates for the responses that had and had not received extinction in their training stimulus, separated according to three conditions: during a same-outcome stimulus, during a different-outcome stimulus, and in the ITI. In general, the presentation of a stimulus augmented responding relative to that seen in the ITI. This was true of both extinguished and nonextinguished responses and for both stimuli [Wilcoxon $Ts(16) \leq 19$, $p < .01$]. Of most interest, the magnitude of this elevation was more substantial for the same-outcome stimulus. This greater elevation by the same-outcome stimulus than by the different-outcome stimulus was reliable for the nonextinguished response [$T(15) = 21$, $p < .05$] and for the response that had been extinguished
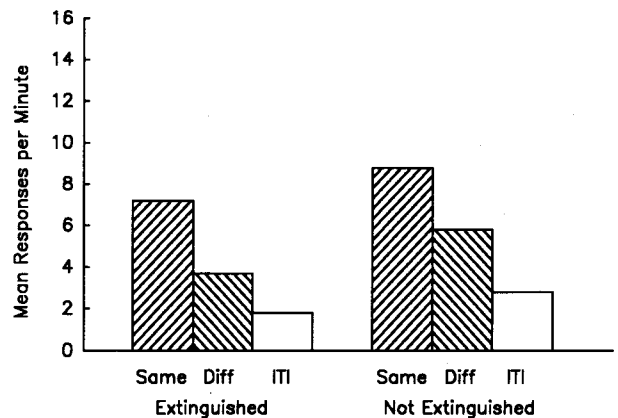

Figure 2. Results of the test session for response–outcome associations in Experiment 1. Responding is shown for previously extinguished and nonextinguished responses in the absence of any stimulus (intertrial interval, or ITI) and in the presence of stimuli signaling the same or different outcomes from those previously earned by the response.

$[T(12) = 0, p < .01]$. Overall, the response rate for the extinguished response was lower than that for the nonextinguished response, but the difference was not reliable. Although the difference in level complicates comparison between extinguished and nonextinguished responses, the magnitude of the *same–different* effect appears similar in the two cases. Statistically, there was no reliable difference in the size of the effect expressed either as simple difference scores or as differences in the ratios of responding during the stimulus to that in the ITI.

These results confirm those previously reported by Rescorla (1991a). A stimulus transfers preferentially to a response trained with the same outcome. Moreover, this transfer remains even when the response has undergone extinction. These observations suggest that the R–O associations are well preserved through extinction.

Transfer of treated stimuli. The results of the second transfer test, when the tone and noise were presented at a time when the nosepoke and handlepull were available, are shown in Figure 3. The figure shows responding for extinguished and nonextinguished stimuli, separated for same-outcome responses, different-outcome responses, and the ITI. The overall rate of responding continued to be higher with the nosepoke and handlepull (which were trained with the visual stimuli) than on the lever and the chain. But it is clear that presentation of a stimulus elevated responding over that observed in the ITI $[Ts(16) < 20, ps < .01]$. Of more interest, this elevation was more substantial when the stimulus signaled the outcome that the response had previously earned. The latter was true of both the extinguished stimulus $[T(16) = 29, p < .05]$ and the nonextinguished stimulus $[T(16) = 28, p < .05]$. The magnitude of the *same–different* effect was statistically similar for the extinguished and nonextinguished stimuli.

These observations confirm those reported by Rescorla (1992b). A stimulus that has signaled a particular outcome
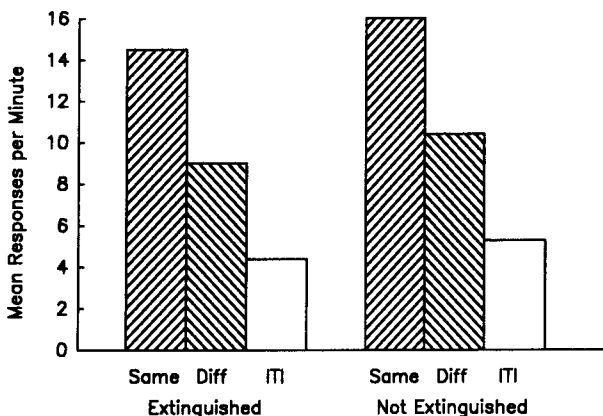

Figure 3. Results of the test session for stimulus–outcome associations in Experiment 1. Responding is shown in the absence of any stimulus (intertrial interval, or ITI) and in the presence of previously extinguished and nonextinguished stimuli that signaled the same or different outcomes from those previously earned by the response.
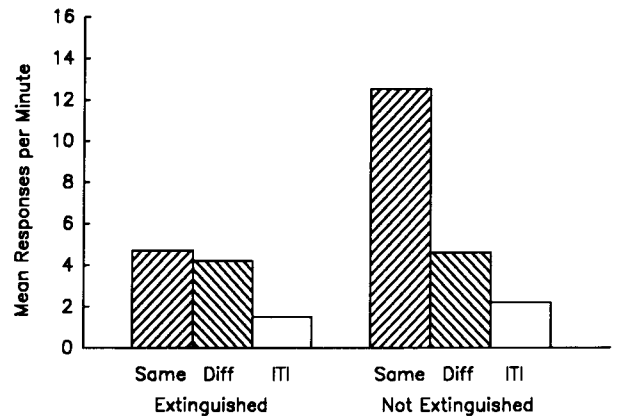

Figure 4. Results of the test of the originally trained discriminations in Experiment 1. Responding is shown for the extinguished and nonextinguished responses when presented with their original (same) stimulus or with another (diff) stimulus.

is especially successful in augmenting a transfer response that has earned the same outcome. Moreover, this is true even if the transfer stimulus has had its own response extinguished in its presence. These results suggest that the S–O association is well preserved through extinction.

Test of trained stimulus–response combinations. Figure 4 shows the results of testing the lever and chain with their original auditory discriminative stimuli, displayed separately for the responses that had been extinguished or not. The results are shown for the stimulus originally used to train each response (*same*) and that used to train the alternative response (*different*). It is clear that the original stimulus (*same*) for the nonextinguished response continued to augment responding, relative to both the ITI and the stimulus signaling a different outcome $[Ts(16) = 6, 17, ps < .01]$. The augmentation produced by the different-outcome stimulus proved nonreliable. By contrast, the extinguished response was not differentially augmented by its original training stimulus, relative to the different-outcome response $[T(16) = 48.5]$. However, the elevation in the extinguished response relative to the ITI proved reliable for both stimuli $[Ts(16) < 17, ps < .01]$. These results verify that extinction severely disrupted performance of the extinguished S/R combination.

The pattern of results observed for the S–O and R–O associations is like that previously observed separately for these associations. Following extinction of a previously trained S/R combination, both the S–O and the R–O associations seem largely intact, as assessed by various transfer tests. Apparently the depression observed in extinction is not primarily the result of these associations' being altered.

However, the present results differ from those from prior experiments in one respect. Each stimulus produced augmentation even of a response that had earned a different outcome. In both of the transfer tests shown in Figures 2 and 3, responding was greater during the different-

outcome stimulus than during the ITI. It seems likely that this result is attributable to generalization between the same-modality stimuli that were used to signal the different outcomes. But it is important to note that the data of primary interest in the present experiments are the differential rates of responding that a stimulus produces for responses trained with the same and different outcomes. That difference reflects the state of the various outcome-based associations. The similarity of pattern of transfer in the extinguished and nonextinguished stimuli and responses is the result that suggests that extinction left those associations intact.

These results confirm that a stimulus continues to show outcome-based transfer to a new response and that a response continues to receive outcome-based transfer from a new stimulus, despite the inability of the stimulus to control the response. This observation suggests that change in the association of neither the stimulus nor the response with the outcome is primarily responsible for the decrement seen in extinction. Instead, there appears to be a decline in the likelihood of a particular response in a particular stimulus. One possible basis is the formation of an inhibitory association between S and R, as suggested by Colwill (1991). Such an association might interfere with response production, despite retention of the associations with O. Experiments 2–4 explore this possibility.

EXPERIMENT 2

The goal of this experiment was to provide an additional evaluation of the possibility that the behavioral decrement resulting from extinction involves some process other than changes in the R–O and S–O association. The idea was to train each of two stimuli, S1 and S2, as signals that each of two responses, R1 and R2, would result in a common outcome. Then two of the S/R combinations, S1R1 and S2R2, were subjected to extinction. Finally, all four S/R combinations were tested.

As a result of the extinction, each stimulus and each response should have individually occurred in the absence of the outcome. To the degree that such exposure simply modifies the individual S–O and R–O associations, one would expect the four S/R combinations to be affected similarly. The S1R1 and S2R2 combinations should have the same individual S–O and R–O associations contributing to their performance as do the S1R2 and S2R1 combinations. However, to the degree that extinction produces an effect that exceeds that on those individual associations and involves the specific S/R combinations nonreinforced, one might expect less performance with the combinations actually presented and nonreinforced.

Method

Subjects and Apparatus

The subjects were 16 male rats of the same origin and maintained in the same manner as in Experiment 1. The apparatus was that of Experiment 1.

Procedure

Initial response training. On the 1st experimental day, all animals received magazine training consisting of the delivery of 20 pellets on a VT 20-min schedule. On the following 2 days, all animals were trained to leverpress and chainpull for pellets, in the manner of Experiment 1. On each of the next 3 days, all animals received two 20-min sessions spaced about an hour apart, one with lever and one with chain. During each session, responding was rewarded with pellets on a VI 60-sec schedule.

Discrimination training. On each of the next 12 days, the animals received discrimination training with light and noise. Each day contained two sessions, spaced about an hour apart, one with lever present and one with chain present. Each session contained sixteen 30-sec presentations each of light and noise, during each of which pellets were available on a VI 30-sec schedule. On the first 3 days, the ITIs were variable around means of 15, 30, and 60 sec. Thereafter they varied around 90 sec. No reward was available during the ITI.

Extinction. On each of the next 5 days, the animals received two extinction sessions. The chain was present during one session and the lever during the other. Each session contained sixteen 30-sec presentations of either the light or the noise. The treatment was balanced so that half the animals received extinction of leverpressing during the noise and chainpulling during the light, whereas the other half of the animals had the alternative S/R pairs.

Test. On the next day, the animals received two test sessions, one with lever and one with chain. During each session, they received four 30-sec presentations each of light and noise, spaced 30 sec apart.

Results and Discussion

Initial response and discrimination training proceeded smoothly. By the final day of training, the mean responses per minute during the stimuli were 17.8, whereas during the ITI they were 1.4. There were no reliable differences as a function of stimulus or response identity. Over the course of extinction, the mean response rates fell to 1.0 and .8 per minute during the stimulus and ITI, respectively.

The results of most interest, from the test session in which all S/R combinations were assessed, are shown in Figure 5. That figure displays the mean responses per
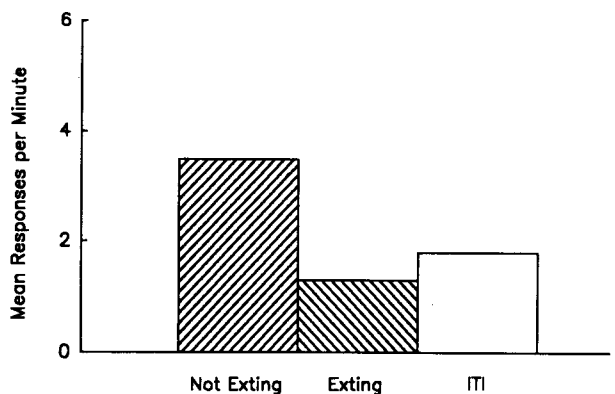
Figure 5. Results of the test session of Experiment 2. Responding is shown in the absence of any stimulus (intertrial interval, or ITI) and in the presence of a stimulus with which the response had or had not received extinction.

minute in three time periods: during the ITI, during the stimulus with which the response had been extinguished, and during the stimulus with which the alternative response had received extinction. It is clear that a stimulus during which the response had been extinguished failed to elevate responding, but a stimulus during which another response had been extinguished did substantially augment responding. Responding during the alternative stimulus was reliably greater than either that during the extinguishing stimulus [$T(16) = 3, p < .01$] or that during the ITI [$T(14) = 18.5, p < .05$]. Responding during the extinguishing stimulus and the ITI did not differ reliably.

These results suggest that there is a special decrement in the S/R combination that undergoes extinction, beyond any loss in the individual S–O and R–O associations. Because each S and each R had been extinguished with *some* companion, any such individual association loss would apply equally well to both types of test trials. Hence the differences observed must be attributable to some special loss for the presented combinations.

One possible interpretation of such results is that extinction produces an inhibitory S–R association that interferes with performance of that response during that stimulus. However, there is an equally plausible, and historically much more popular, possibility—the reduction of previously trained excitatory S–R associations. Although the training procedures used here have repeatedly been shown to result in the establishment of S–O and R–O associations, there is reason to believe that they may also produce S–R associations. The response is repeatedly reinforced in the presence of the stimulus, thereby satisfying the conditions normally assumed to establish S–R associations. To the degree that these S–R associations help support performance, it is possible that their reduction could be responsible for much of the decrement observed in extinction.

This second alternative is made plausible by the fact that all four S/R combinations were trained originally, possibly establishing four relatively independent S–R associations. Then extinction need only reduce two S–R associations, leaving the other two intact, to produce the results observed here. One way to reduce the plausibility of that account would be to remove this opportunity for the initial establishment of excitatory S–R associations. That was the intention of Experiment 3.

EXPERIMENT 3

The design of Experiment 3 was like that of Experiment 2, except that neither of the responses of interest was originally rewarded in the presence of either stimulus. As illustrated in Figure 6, each animal received extinction of one response in one stimulus and the other response in a second stimulus. Testing was then conducted with all four S/R combinations. However, instead of training these S/R combinations, the experiment took advantage of the transfer paradigm to guarantee that the responses would initially be made during the stimuli. The L and N were trained as discriminative stimuli for a com-

Discrim	Train	Extinction	Test
N: Rc–P	R1–P	L: R1–, N: R2–	N
L: Rc–P	R2–P	L: R2–, N: R1–	L R1, R2

Figure 6. Design of Experiment 2. Discrimination training was given with two stimuli, noise (N) and light (L), during which a common response (Rc) led to pellets (P). Two additional responses, R1 and R2, were trained with pellets and then each was extinguished in the presence of either L or N. All animals were then tested for both responses during both stimuli.

mon nosepoke response, Rc, using a pellet reward. Then both a leverpress and a chainpull, R1 and R2, were allowed to earn pellets on a simple VI schedule. During extinction, each animal received nonreinforcement of leverpress and chainpull, each in the presence of one of the stimuli. Finally, each S/R pair was tested.

Because both stimuli had signaled that Rc would yield pellets, it was anticipated that leverpressing and chainpulling would occur with reasonable frequency during those stimuli at the beginning of extinction. However, because neither response had been rewarded during either stimulus, the conventional conditions for the establishment of excitatory S–R associations have been minimized. Consequently, any S/R combination-specific performance decrement would seem less likely to be attributable to the reduction of previously established excitatory S–R associations and more likely to be due to the development of inhibitory learning.

Method

Subjects and Apparatus

The subjects were 16 male rats of the same origin, maintained in the same manner as in Experiment 1. The apparatus was that of Experiment 1.

Procedure

Initial training. Initial response training was like that of Experiment 2. After a day of magazine training, all animals were successively trained to leverpress, chainpull, and nosepoke for pellets over the next 3 days. On each of the next 2 days, they received a 20-min session during which nosepoke was rewarded on a VI 60-sec schedule.

Discrimination training. On each of the next 14 days, the animals received discrimination training during which nosepoking was rewarded by pellets in the presence of both the light and the noise. Each session contained sixteen 30-sec presentations each of light and noise, during which a VI 30-sec schedule was in effect. The ITI was variable around means of 30, 60, and 90 sec over the first 3 days; thereafter, it varied around 90 sec.

Target response training. On each of the next 5 days, the animals received VI training with the leverpress and chainpull. Each day contained two 20-min sessions, during each of which a VI 60-sec schedule was in effect. The lever was available in one session and the chain in the other.

Extinction. On each of the next 4 days, the animals received two extinction sessions. Each session contained sixteen 30-sec presentations of either the light or the noise, with a 30-sec ITI. The lever was present in one session and the chain in the other. Half the animals were exposed to the noise–lever and light–chain combinations; the remaining half of the animals received the alternative combinations.
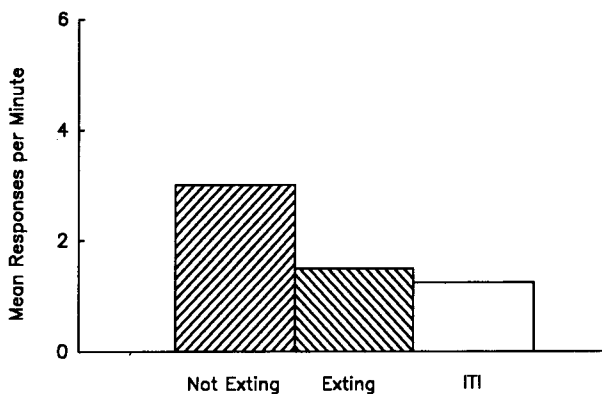
Test. On the next day, each animal received two test sessions, each of which contained four 30-sec presentations each of light and noise, spaced 30 sec apart. The lever was available during the first session and the chain was available during the second session.

Results and Discussion

Initial discrimination and response training proceeded smoothly. By the final day of discrimination training with nosepoke, the mean responses per minute were 54.2, 55.8, and 8.6 during the light, the noise, and the 30-sec prestimulus period, respectively. The mean responses per minute on the final day of VI training with lever and chain were 10.3. From the first to the last day of extinction, the mean rates of responding dropped from 7.8 to 1.6 during the stimulus and from 5.2 to 1.3 during the 30-sec prestimulus period. The initial elevation of responding produced by the stimulus was highly reliable [$T(16) = 0$, $p < .01$]. That elevation is presumably mediated by the S–O and R–O associations set up during separate training of the stimulus and response.

The results of most interest, from the test of both responses in the presence of both stimuli, are shown in Figure 7. That figure shows the mean responses per minute during a 30-sec stimulus and 30-sec prestimulus period for stimuli in the presence of which the response had been extinguished or not. It is clear that the stimulus in which the response had been extinguished did little to elevate responding. However, a stimulus during which the response had been neither trained nor extinguished produced substantial elevation. The level of responding during that stimulus was greater than that during the prestimulus period [$T(15) = 4$, $p < .01$] and during the extinguished stimulus [$T(15) = 3$, $p < .01$].

These results confirm the findings of Experiment 2 that there is some decrement in responding that was specific to the S/R combination that was nonreinforced in extinction. More importantly, they do so for S/R combinations that have never previously been rewarded and therefore for which little in the way of excitatory S–R associations should exist. The elevation of responding shown initially during extinction indicates the presence of the S–O and R–O associations, as has been observed in prior work. However, the combination-specific decrement in responding suggests that superimposed on those outcome-based associations is an inhibitory association between S and R.

EXPERIMENT 4

Experiments 2 and 3 suggest the development of an inhibitory association between S and R, as indexed by reduction in the ability of the stimulus to produce a particular response. Each experiment used a pretraining procedure that allowed the stimulus to enhance responding. Experiment 2 accomplished this by direct reinforcement of the response during the stimulus, whereas Experiment 3 exploited the ability of a stimulus signaling a shared outcome to enhance the response. This initial enhancement of responding during the stimulus has the advantage that it allows documentation that the stimulus is adequately processed during extinction. However, it has the disadvantage of providing an elevated baseline of responding. As a result, the impact of extinction was simply to remove the response-evoking ability of the stimulus. Consequently, these experiments provided no evidence that extinction produced a net inhibitory association between S and R, as reflected in the ability of the stimulus to reduce the likelihood of that response below its ambient level.

Experiment 4 was intended to detect such a net inhibitory S–R association. To this end, Experiment 3 was repeated, but without any pretraining of the stimulus. Under those circumstances, one would not expect the stimulus to show an initial enhancement of the responding. Hence, any response-specific depressive power that the stimulus gained could be evidenced in reduction relative to the ongoing response rate.

Method

Subjects and Apparatus

The subjects were 16 male rats of the same origin and maintained in the same manner as in Experiment 1. The apparatus was that of Experiment 1.

Procedure

Initial training. Initial response training was like that of Experiment 2. After a day of magazine training, all animals were trained to leverpress and chainpull for pellets. On each of the next 5 days, they received VI training with the leverpress and chainpull. Each day contained two 20-min sessions, during each of which a VI 60-sec schedule was in effect. The lever was available in one session and the chain in the other.

Extinction. On each of the next 5 days, the animals received two extinction sessions. Each session contained sixteen 30-sec presentations of either the light or the noise, with a 10-sec ITI. The shorter ITI was used in order to guarantee a substantial level of responding during the stimuli before responding ceased altogether. The lever was present in one session and the chain in the other. Half the animals were exposed to the noise–lever and light–chain combinations; the remaining half of the animals received the alternative combinations.

Figure 7. Results of the test session of Experiment 3. Responding is shown in the absence of any stimulus (intertrial interval, or ITI) and in the presence of a stimulus with which the response had received extinction or not.

Retraining. On the next day, all animals received retraining of both lever and chain, in the manner of initial training. The intention of this training was to arrange for a moderate rate of responding so that any response-specific depressive effects could be observed during the stimulus presentations of the subsequent test. No stimuli were present during these retraining sessions.

Test. On the next day, each animal received two test sessions, each of which contained four 30-sec presentations each of light and noise, spaced 30 sec apart. The lever was available during the first session and the chain was available during the second session.

Results and Discussion

Initial response training proceeded smoothly. The mean responses per minute on the final day of VI training with lever and chain was 7.3. From the first to the last day of extinction, the mean rates of responding dropped from 3.8 to 1.2 during the stimulus and from 4.3 to 1.1 during the 10-sec prestimulus period. There were no reliable differences between responding in the CS and pre-CS periods during the course of extinction. During retraining, the mean response rates returned to moderate levels, reaching 7 responses per minute in the final 5 min of the session.

The results of most interest, from the test of both responses in the presence of both stimuli, are shown in Figure 8. That figure shows the mean responses per minute during 30-sec stimulus and 30-sec prestimulus periods for stimuli in the presence of which the response had been extinguished or not. There was a moderate level of responding in the absence of any stimulus. Presentation of the stimulus with which a response had not been extinguished resulted in little change in response rate. However, presentation of the stimulus with which the response had been extinguished reduced the response rate. Responding during the extinguished stimulus was reliably below both that during the ITI and that during the nonextinguished stimulus [$Ts(13) = 6$ and 5, respectively, $ps < .01$]. There was no reliable difference between responding during the ITI and that during the nonextinguished stimulus [$T(14) = 41.5$].
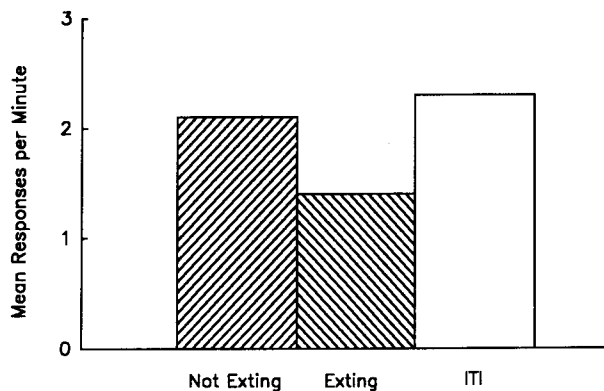
Figure 8. Results of the test session of Experiment 4. Responding is shown in the absence of any stimulus (intertrial interval, or ITI) and in the presence of a stimulus with which the response had received extinction or not.

These results suggest that nonreinforcement of a response during a stimulus can give that stimulus the ability to specifically depress that response. As in prior experiments, each of two stimuli and each of two responses had received extinction. Nevertheless, some of the observed decrement was apparently a property of specific S/R combinations. Unlike in prior experiments, the present results suggest that a net inhibitory association can develop between a specific S and a specific R.

The treatment used in this experiment is formally similar to that of earlier Pavlovian and instrumental experiments in which a neutral stimulus is present during extinction of either another stimulus (e.g., Rescorla, 1979) or a response (e.g., Daly, 1974; Wagner, 1966). In those earlier experiments, the intention was to have a neutral stimulus present at a time of nonreinforcement so that the consequences of that nonreinforcement might become conditioned to the stimulus. In particular, the goal was to detect the occurrence of some general inhibitory (Rescorla, 1979) or aversive frustrative (Daly, 1974; Wagner, 1966) process. Those experiments were indeed successful in identifying the conditioning of some general decremental process to the stimulus. Such a stimulus comes to inhibit other conditioned stimuli paired with the same outcome as well as to acquire some general aversive properties. Presumably the stimuli used in the present experiment also develop such properties. But the design of the present experiments was such as to expose instead a decremental process that was more specific to a particular response.

GENERAL DISCUSSION

These experiments provide evidence for the contribution of some S/R specific process in extinction. Experiment 1 confirmed earlier reports that extinction leaves the S-O and R-O associations largely intact. Despite the fact that a stimulus loses the ability to evoke its own response, it continues to transfer to other responses based on a shared outcome. Moreover, its response continues to accept transfer from other stimuli also based on that shared outcome. Experiments 2-4 provide more direct evidence that any changes in the R-O and S-O associations that might occur in extinction fail to provide a full account of the decrement observed. They found that S/R combinations that had equivalently treated S-O and R-O associations nevertheless showed quite different levels of performance, depending on whether or not the particular combinations had received explicit extinction.

One possibility for such an S/R specific process would be the loss of excitatory S-R associations established during training. Despite the identification of S-O and R-O associations, such S-R associations might normally contribute to performance but be attenuated as a result of extinction. However, two observations make that possibility less attractive. First, the simple removal of excitatory S-R associations would leave intact the S-O and R-O associations that can be detected by transfer. But since those outcome-based associations are sufficient to generate

transfer, it is unclear why they could not also continue to produce the original discriminated performance of R in S. Colwill (1992) has provided evidence that these S–O and R–O associations do in fact contribute to that original performance. Consequently, simple removal of the S–R association should leave that contribution intact to support continued performance during extinction. Apparently, any change in the S–R association must involve a more actively inhibitory process that interferes with the original performance. Second, Experiments 3 and 4 found evidence for an S/R specific decremental process despite the absence of previously trained excitatory S–R associations. That suggests that extinction does not simply attenuate excitatory associations.

This makes more attractive a second possibility, that nonreinforcement of R in S establishes an active inhibitory association between the two, as suggested by Colwill (1991). Repeated nonreinforced occurrence of a response during a stimulus may give that stimulus the power to reduce the occurrence of the response. The most elementary alternative is that S develops a direct inhibitory association with R. But one might also consider more complex alternatives involving hierarchical structures. It could be, for instance, that S develops an inhibitory association with the R–O relation, effectively signaling that R would not be rewarded in its presence. There is evidence that S can develop an excitatory association with that relation (e.g., Rescorla, 1991b). Perhaps it can also develop a parallel inhibitory association. There is nothing in the present results to separate the simple S–R from the more complex S–(R–O) possibility.

The notion that S might signal the absence of a specific R–O relation has clear parallels in the Pavlovian occasion-setting literature. There, conditioned inhibitors are sometimes described as signaling the absence of an excitatory relation between a CS and a US (e.g, Holland, 1985; Rescorla, 1992b). Similarly, some instances of contextual control over responding have been characterized in this fashion (e.g., Bouton, 1991). In effect, the present observation is that an inhibitor established by extinction of a response in its presence shows a specific effect on that response without complete transfer to another response. The feature that makes the present observation especially powerful is that comparison is made with other S/R combinations whose elements are otherwise equivalently treated.

Pavlovian modulatory results of this sort can also be described in terms of configural cues, in which a particular combination of stimuli signals an outcome or its absence. Although many have favored a hierarchical description in which one stimulus affects the performance to another, the configural stimulus view has proven difficult to reject. Similarly, in the present case of instrumental learning, one could describe the results in terms of a configural S/R stimulus signaling the absence of the outcome. Such a configural description may seem less natural for the case in which one element is a stimulus and the other

a response; but there is nothing in the present results to rule it out.

It should be emphasized that nonreward also has more general effects on the response. The overall likelihood of a response appears to be depressed by extinction. Indeed, many of the transfer experiments, such as the present Experiment 1, have routinely acknowledged this by retraining extinguished responses with a common alternative reward prior to the test. Moreover, in addition to the stimulus-specific inhibitory process identified in Experiments 2 through 4, there is clearly a general depression of responding. Some of the performance decrement appears to be an overall outcome-independent change in the response. One possibility is that nonreinforced responses become associated with the frustration that results from nonreward, a frustration that is relatively independent of the quality of the previously used reward. Another possibility is that the context acquires an ability to inhibit the response in much the same way as does an explicit stimulus. The present results do not allow a choice between those alternatives.

But what the present experiments do suggest is that there is some decremental process that goes beyond general depression of the response or the stimulus and is specific to their combination.

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