Negative discriminative stimuli provide information about the identity of omitted response-contingent outcomes

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Three experiments using rats examined whether a signal for the nonreinforcement of an instrumental response (S⁻) provided information about the identity of the omitted outcome. In all three experiments, one stimulus was established as a signal for the nonreinforcement of a response that earned food pellets and another stimulus signaled the nonreinforcement of a response that earned liquid sucrose. Experiment 1 found that each S⁻ suppressed another instrumental response trained with the same outcome significantly more than a response trained with a different outcome. Using a variant of this transfer design, Experiment 2 demonstrated that an S⁻ was slower to develop discriminative control over a new response reinforced in its presence with the same outcome compared with an outcome different from the one whose omission the S⁻ had previously signaled. Experiment 3 examined transfer of the S⁻ stimuli to a response trained with two outcomes, one of which had subsequently been devalued. Performance of this response significantly increased in the presence of a signal for the omission of the devalued outcome, but decreased in the presence of a signal for the omission of the valued outcome. These results suggest that S⁻s do provide information about the identity of omitted response-contingent outcomes.

In recent years, considerable progress has been made in identifying the associative connections underlying instrumental behavior. It is now clear that the organism forms associations between the reinforcing outcome (O) and both the instrumental response (R) and the discriminative stimulus (S⁺). Of particular relevance to the present paper, Colwill and Rescorla (1988) used a transfer paradigm to demonstrate that S⁺s become associated with the particular outcomes that are earned in their presence. They found that an S⁺ trained with one response-outcome relation would selectively promote other instrumental responses trained with the same outcome, while leaving unaffected responses trained with different outcomes. Thus, stimuli that signal the occurrence of a response-contingent outcome provide information about the identity of that outcome.

The present experiments were designed to extend this analysis to discriminative stimuli that signal the omission of a response-contingent outcome (S⁻s). Just as an S⁺ signals a positive relation between a response and an outcome, an S⁻ signals a negative relation. Accordingly, it might be expected that just as an S⁺ provides informa-

tion about the identity of the outcome earned in its presence, an S⁻ might provide analogous information about the omitted outcome. For this purpose, these experiments employed the basic transfer paradigm used by Colwill and Rescorla (1988). Two stimuli were trained as S⁻s, one as a signal (S1) that a response (R1) would not be reinforced with one outcome (O1), and the other as a signal (S2) that a response (R2) would not be reinforced with a different outcome (O2). In order to assess the outcome-specific encoding of these S⁻s, they were presented in conjunction with two different instrumental responses, one (R3) trained with O1 and one (R4) trained with O2. The presence of such associations would be revealed by the ability of an S⁻ to depress selectively the response trained with the outcome that the S⁻ had previously signaled would not occur. Specifically, performance of R3 should be depressed in the presence of S1, whereas performance of R4 should be lowered in the presence of S2.

EXPERIMENT 1

This experiment assessed the ability of a stimulus that signaled the omission of a response-contingent outcome to suppress another instrumental response trained with that outcome. Rats were trained to make two different instrumental responses, handle pull and nose poke, for two different outcomes, sucrose and pellets. The two responses were trained in separate sessions and on different days. Each session also contained presentations of an S⁻, a noise or a light, during which responding was never reinforced. One stimulus, S1, indicated that one of the responses, R1,

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S- training	Transfer	Test
R1→O1, S1: R1→O1	R3→O1, Sc: R3→O1	S1: R3 v R4
R2→O2, S2: R2→O2	R4→O2, Sc: R4→O2	S2: R3 v R4

Figure 1. Design of Experiment 1: R1, R2, R3, R4 are instrumental responses (nose poking, handle pulling, leverpressing, and chain pulling); S1, S2, and Sc are negative discriminative stimuli (noise, light, and tone + flashing-light compound); O1 and O2 are reinforcers (sucrose and pellets).

would not be reinforced with pellets; the other stimulus, S2, indicated that the other response, R2, would not be followed by sucrose. Then two new responses, leverpress and chain pull, were trained, one, R3, with pellets, and the other, R4, with sucrose. Finally, R3 and R4 were made available in an extinction test with periodic presentations of S1 and S2. This design is outlined in Figure 1. It was predicted that if the subjects had learned which reinforcer would not occur during the S—s, then S1 would selectively depress R3, the response that was trained with pellets, and S2 would selectively depress R4, the response that was trained with sucrose.

In order to enhance detection of transfer, the transfer responses were trained with a common S— (Sc). Several investigators have reported that the transfer of Pavlovian discriminative stimuli that provide information about the reinforcement of simple conditioned stimuli is improved by bringing the target stimuli under conditional control (Holland, 1989; Lamarre & Holland, 1987; Rescorla, 1985, 1988). For instance, Lamarre and Holland (1987) found that a stimulus that had been used to signal the non-reinforcement of a Pavlovian excitator suppressed other excitators with a similar training history, but had no impact on a stimulus with a history of simple reinforcement. Given the similarity between the procedures used to train Pavlovian and instrumental discriminative stimuli, it was expected that this treatment might aid detection of the transfer of an S— across instrumental responses.

Method

Subjects. The subjects were 15 experimentally naive Sprague-Dawley male rats (Holtzman Co.) about 100 days old at the start of the experiment. They were maintained in individual cages at approximately 80% of their free-feeding weight. Water was available on an ad-lib schedule.

Apparatus. The apparatus consisted of eight identical Skinner boxes measuring 22.9×20.3×20.3 cm. The two end walls of the chamber were aluminum, and the side walls and ceiling were made of Plexiglas. Each chamber had a recessed food magazine in the center of one end wall. A small metal cup measuring 1.25 cm in diameter and 1.5 cm deep was sunk in the floor of each food magazine. Each box was equipped with four manipulanda: a lever, a chain pull, a nose poke, and a handle pull. The lever was mounted 9 cm above the grid floor and 2.5 cm from the left wall of the food magazine. The chain was suspended from a microswitch mounted on the roof of the chamber. The end of the chain was 11 cm from the grid floor and 3 cm from the right wall of the food magazine. Located 5.5 cm directly above the roof of the magazine was the nose-poke manipulandum, which consisted of a circular aperture 2 cm in diameter and 1.3 cm deep. The back of this aperture was cov-

ered by a metal plate that operated a microswitch whenever it was depressed. Mounted on the same side of the chamber as the chain but 1.5 cm below the grid floor was the handle-pull manipulandum. This consisted of a short, flat rod protruding 3 cm into the chamber. The end of the rod had been bent back to form a handle 2 cm long. Whenever the handle was pulled upward, a microswitch was closed and a response recorded. The same model of microswitch (Unimax Switch Co., 2HBT-1) was used to detect responding on all four manipulanda. Access to these manipulanda was prevented by covering the lever with a metal plate, by retracting the chain through an opening in the ceiling, by inserting a jeweled light cover into the aperture of the nose-poke manipulandum, and by withdrawing the arm of the handle pull. The floor of the chamber was composed of 0.48 cm stainless steel rods spaced 1.9 cm apart. Each Skinner box was enclosed in a sound- and light-resistant shell. Mounted on the inside wall of each shell was a speaker that permitted presentation of a white noise (N), measuring approximately 76 dB re 20 μ N/m², a speaker that permitted presentation of an 1800-Hz tone measuring approximately 76 dB re 20 μ N/m², and a 6-W light (L). Another 6-W light (F) was mounted on the rear wall of the chamber close to the grid floor. It was flashed at the rate of 2.5 cycles per second (cps). The noise and the steady light served as the target S—s, and a compound of the tone and flashing light served as the common S— for the transfer responses. Experimental events were controlled and recorded automatically by relays and a microprocessor located in an adjoining room.

Procedure. All subjects received one session of magazine training consisting of the delivery of 10 45-mg food pellets (Formula A, P. J. Noyes Co.), followed by 10 presentations of 0.3 ml of 8% sucrose liquid on a variable time (VT) 60-sec schedule. In this and all subsequent phases, the delivery of a pellet was always signaled by a distinct click of the pellet dispenser; delivery of sucrose was accompanied by a brief buzzer. During this phase, the response manipulanda were inaccessible to the animals.

Following magazine training, all animals were trained, in separate sessions, to nose poke and handle pull. Initially, each response was reinforced until 50 reinforcers had been obtained. Each response was then reinforced on a variable interval (VI) 30-sec schedule for four 20-min sessions. Half the animals were trained to nose poke for pellets and handle pull for sucrose; the remaining animals experienced the reverse contingencies.

S— training. There were 16 sessions of training, with each response arranged in a double alternating schedule. Each session contained 32 30-sec presentations of either a light or a noise S— stimulus with a mean intertrial interval (ITI) of 30 sec. Responding was reinforced on a VI 30-sec schedule during the ITI, but was never reinforced during the S— stimuli. The identity of the stimulus to be used as the S— for each response–outcome pair was balanced across animals. For 7 animals, light served as a signal for the omission of pellets and noise as a signal for the omission of sucrose; for the remaining 8 animals, these relations were switched.

Transfer training. Two new responses, leverpress and chain-pull, were reinforced, one with pellets and one with sucrose. Initially, subjects were permitted to earn 50 reinforcers, first for leverpressing and then, in a separate session, for chain pulling. Following

this, each response was trained separately on a VI 30-sec schedule for one 20-min session. These responses were then brought under the control of a common S— stimulus, a 30-sec tone-flashing-light compound. Each session contained 32 presentations of the common S— with an ITI of 30 sec. Only one response was available in each session, and responding was reinforced on a VI 30-sec schedule in the absence of the S—. There were four sessions of training with each response.

Testing. In the first two tests, both the lever and chain were available, although responding was never reinforced. The light and noise S—s were each presented four times in the following sequence, NLLNLLNL. The ITI was 30 sec. The third test was identical to the first two, except that the nose-poke and handle-pull responses replaced the lever and chain and there were twice as many presentations of each S—.

Results and Discussion

Over the course of S— training, the subjects came to respond primarily in the absence of the noise and light S—s. In the final session of training, the mean rate of responding, collapsed across response, outcome, and stimulus identity, was 19 per minute in the absence of the S—s and 7 per minute in the presence of the S—s [$T(15) = 0, p < .01$]. Although neither stimulus nor response identity significantly affected responding, the identity of the outcome did influence the level of responding. Pellets supported a higher rate of responding than sucrose in the absence of the S—s, 26.0 and 11.6 per minute [$T(15) = 13, p < .05$]. This difference was also observed in the presence of the S—s, 10.3 and 3.8 per minute [$T(15) = 11.5, p < .05$].

Training of the transfer responses proceeded uneventfully. The common S— compound developed the ability to suppress responding over the course of training. During the final cycle, the mean rate of responding during the compound was substantially lower than the rate during the ITI (4.6 and 9.7 responses per minute, respectively) [$T(15) = 0, p < .01$]. There was no significant effect of either response or reinforcer identity.

The results of most interest are shown in Figure 2. Responding during the first test session is shown separately when the outcome earned by the response was the same as the outcome whose omission was signaled by the S— (filled circles), and when that outcome was different (open circles). Both stimuli produced a decrease in responding compared with the rate during the ITI [$Ts(15) = 19.5, ps < .05$]. However, what is more important is that responding was depressed more by the presentation of a signal for the omission of a reinforcer earned by that response than by a signal predicting the omission of a different outcome. Analysis of the first trial revealed significantly fewer same-reinforcer responses than different-reinforcer responses [$T(15) = 13.5, p < .01$], but an overall analysis just failed to find this difference significant [$T(15) = 30.5, p > .05$]. Further analysis of the data indicated that the identity of the reinforcer had no significant effect on the magnitude of this difference. The results of the second test were similar, but not significant.

These data indicate that responding will be depressed more by a stimulus that predicts the omission of the rein-

Figure 2. Mean responses per minute during the first transfer test in Experiment 1. Responding is plotted separately in the presence of an S— that signaled omission of the SAME outcome as that earned by the response (filled circles), in the presence of an S— for a DIFFERENT outcome (open circles), and during the ITI (dashed line).

forcer earned by the response than the omission of a different reinforcer. It is evident, however, that an S— also suppressed, though to a lesser degree, responding trained with a different outcome. That suppression may reflect the operation of either unconditioned effects or generalization from the compound S—. On the other hand, its origin may be associative. It is not implausible that the training procedure used in the present experiment may have allowed the S—s to predict the absence of both reinforcers, albeit differentially. To the degree that approach to the magazine to collect the reinforcer constitutes an instrumental response, one might argue that the two stimuli are instrumental inhibitors of both outcomes and vary only in the strength with which the omission of those outcomes is signaled.

Consistent with this possibility are the results of the third test, in which the S—s were presented with the original responses, nose poke and handle pull. Over the test, the mean rate of responding during the ITI was 7.3 responses per minute. Not surprisingly, the S— suppressed the response with which it had been trained (2.2 responses per minute) throughout the test session [$T(15) = 1, p < .01$]. However, it also suppressed the other response that had earned a different outcome (4.4 responses per minute) [$T(14) = 0, p < .01$]. Suppression of that response was not as great as suppression of the original response [$T(13) = 16.5, p < .05$]. It is not possible to ascertain, however, whether the incompleteness of this transfer is due to response or reinforcer specificity.

The findings of Experiment 1 indicate that S—s preferentially transfer to new instrumental responses trained with the same outcome. Responding was depressed more by a stimulus signaling the omission of the outcome earned by the response than by a stimulus signaling the omis-

sion of a different outcome. These results indicate that stimuli that signal the nonreinforcement of an instrumental response encode information about the identity of the omitted outcome and that this information is used to modulate instrumental performance. These findings are consistent with the results reported by Bonardi (1989), who used a retardation test to measure the reinforcer specificity of S-s. In her study, rats were rewarded for leverpressing in the presence of S1 with O1 and in the presence of S2 with O2. Occasionally, S1 and S2 were presented in compound with S3 and S4, respectively. During these compounds, leverpressing was never reinforced. Thus, S3 signaled the omission of O1 and S4 signaled the omission of O2. Following this, S3 and S4 were converted into S+s for O1 and O2. For half the animals, S3 signaled O1 and S4 signaled O2, the outcomes whose omission they had previously signaled; for the remaining animals, these contingencies were switched. The fact that the S-s had encoded information about the identities of the omitted outcomes was revealed by slower acquisition of S+ control when the outcomes occurring during the S-s were the same as those that had previously been omitted during those S-s.

EXPERIMENT 2

This experiment combined the transfer procedure of Experiment 1 with the retardation procedure used by Bonardi (1989) to detect encoding of the identity of the omitted outcome by an S-. The design is shown in Figure 3. As in Experiment 1, two stimuli were initially established as S-s, one for the omission of pellets and one for the omission of sucrose. Then both stimuli were transferred to a new response (R3) that earned one of those outcomes only in the presence of the S-s. For half the animals, R3 earned O1, and for the others, R3 earned O2. It was expected that acquisition of discriminative control over R3 would be slower for the S- that had previously signaled the omission of the outcome that was subsequently earned by R3.

The design of Experiment 2 also permitted an examination of the effect of converting an S- into an S+ on its ability to suppress its original responses. To the degree that this suppression is mediated by the same mechanism that produces transfer of suppression, it would be expected that the S-s would differentially control their original responses. Specifically, the response used to establish an

S- should be less suppressed if that S- now signaled the availability of the outcome used to train that response. In fact, given the findings of Colwill and Rescorla (1988), performance of this response might even be promoted by its former S-. To test this possibility, all animals were given separate extinction tests with R1 and R2. During each test, there were occasional presentations of S1 and S2.

Method

Subjects. The subjects were 16 experimentally naive Holtzman-derived Sprague-Dawley male rats (Harlan Co.) about 100 days old at the start of the experiment. Conditions of housing and maintenance were the same as those described in Experiment 1.

Apparatus. The apparatus consisted of eight Skinner boxes built to the same specifications as those used in Experiment 1. There were, however, two major differences. First, the sucrose was delivered through a tube inserted through the roof of the food magazine. Each operation of the sucrose dispenser allowed 0.2 ml of 8% sucrose to flow onto the floor of the food magazine, where it collected in a shallow indentation. Second, the lever was mounted 2.5 cm from the right wall of the food magazine and the chain was suspended 3 cm from the left wall of the food magazine. Furthermore, four of the boxes contained a retractable lever that was withdrawn to prevent access to it. Experimental events were controlled and recorded automatically by interfacing (Med Associates) and an XT microprocessor located in an adjoining room.

Procedure. All subjects received one session of magazine training consisting of the delivery of 10 45-mg food pellets (Formula A, P. J. Noyes Co.), followed by 10 presentations of 0.2 ml of 8% sucrose liquid on a VT 60-sec schedule. In this and all subsequent phases, a brief click accompanied operation of the pellet and sucrose dispensers. During this phase, the response manipulanda were inaccessible to the animals.

Following magazine training, all animals were trained to nose poke and handle pull for either pellets or sucrose. In the first session, nose poking was reinforced with pellets (or sucrose) until 30 reinforcers had been earned; in the second session, handle pulling was reinforced with sucrose (or pellets) until 30 reinforcers had been earned. Each response was then reinforced on a VI 30-sec schedule for three separate 20-min sessions. Nose poking was trained in sessions 1, 4, and 6, and handle pulling in sessions 2, 3, and 5.

S- training. There were 14 sessions of training with each instrumental response. Details of the training procedure are identical to those reported in Experiment 1. The combinations of stimuli and response-no-outcome relations were balanced across animals. Thus, for each animal, one stimulus signaled the omission of pellets and the other stimulus signaled no sucrose.

S+ training. Chain pulling was trained with pellets for half the animals and with sucrose for the remaining animals. Assignment of subjects to these treatments was balanced across the combinations of stimuli, responses, and outcomes arranged in S- training. In the first session, responding was reinforced on a continuous reinforcement (CRF) schedule until 30 reinforcers had been earned.

S- training	S+ training	Test
R1->O1, S1: R1->O1	S1: R3->O1, S2: R3->O1	S1: R1 S2: R1
R2->O2, S2: R2->O2	S1: R3->O2, S2: R3->O2	S1: R2 S2: R2

Figure 3. Design of Experiment 2: R1, R2, and R3 are instrumental responses (nose poking, handle pulling, and chain pulling); S1 and S2 are discriminative stimuli (noise and light); O1 and O2 are reinforcers (pellets and sucrose).

Then responding was trained on a VI 30-sec schedule for 4 20-min sessions. For the next 16 sessions, responding was reinforced only in the presence of the light and noise S-s. Each session contained 16 presentations of each stimulus. For the first 8 sessions, the ITI was 30 sec; it was increased to 60 sec for the next 4 sessions and then to 90 sec for the last 4 sessions. Thus, for each animal, one S- (SAME) was trained to signal the availability of an outcome for chain pulling that was the same as the outcome whose omission it had signaled for a different response; the other S- (DIFF) signaled an outcome for chain pulling that was different from the outcome whose omission it had previously signaled.

Testing. To ensure speedy location of the original responses during the tests with the S-s, all animals received an 8-min session of VI 30-sec training with each response. The test sessions contained four 30-sec presentations of the noise S- intermixed with four 30-sec presentations of the light S-. The ITI was 30 sec. Only one response was available in a test session, and responding was never reinforced. Each response was tested once a day for 2 days. Between the first and second pair of test sessions, each response was extinguished for 10 min to reduce the overall level of responding.

Results and Discussion

By the end of S- training, the rate of responding in the presence of the stimuli was substantially lower than in their absence. In the final session of this phase, the mean stimulus and ITI rates were 8.5 and 26.0 responses per minute, respectively [$T(16) = 0$, $p < .01$]. All subjects learned to chain pull. By the last session of VI training, the mean rate was 11.0 responses per minute.

Conversion of the S-s to signals for the reinforcement of chain pulling was slightly but significantly retarded for the stimulus that had signaled the omission of an outcome that was the same as that earned by the chain-pull response. Mean discrimination ratios were calculated for each session by dividing the mean responses per minute during the stimulus by the mean responses per minute during the stimulus and the ITI. Over the first four sessions, the mean discrimination ratio was 0.46 for the S- trained with the same outcome and 0.50 for the S- trained with a different outcome [$T(14) = 19$, $p < .05$]. This difference disappeared over the course of training, and by the final session the mean discrimination ratios for the *same* and *different* conditions were identical (0.79).

This result is similar to that reported by Bonardi (1989), who found evidence of retardation when the original response was used in both phases. It reinforces the conclusions of Experiment 1 and provides additional evidence that S-s provide information about the identity of omitted outcomes.

Of further interest are the results of testing the S-s with their original responses. Figure 4 shows the data from the first test session. The left panel plots responding during the SAME S- (solid bar) and during the ITI (open bar). The right panel shows a similar plot for responding during the DIFF S- (solid bar) and during the ITI (open bar). In both cases, the S- clearly depressed the response with which it had originally been trained relative to the ITI [$Ts(16) = 0$, $p < .01$]. What is especially intriguing is that the amount of suppression was not significantly affected by the identity of the outcome used to train the S-s

Figure 4. Mean responses per minute during the test of the S-s with their original responses. SAME S- indicates the stimulus trained as an S+ for the same outcome whose omission it had previously signaled; DIFF S- indicates the stimulus trained as an S+ for a different outcome from the one whose omission it had formerly signaled. Responding during the S- is shown by the solid bar and in the absence of the S- by the blank bar (ITI).

as S+s. Converting an S- for one outcome into an S+ for the same outcome did not alter its ability to suppress its own response relative to an S- trained as an S+ for a different outcome. The second test generated similar results. The preservation of response suppression by an S- converted to an S+ for the same outcome suggests that an S- controls the response with which it was trained through a mechanism additional to the one used to mediate transfer across new instrumental responses. One obvious possibility for such an additional mechanism is that S- training leads to an inhibitory association between the S- and the response that is nonreinforced in its presence. Furthermore, that inhibitory S-R association is sufficiently powerful to mask completely the S-O association established by S+ training.

On the basis of Colwill and Rescorla's (1988) study, it was anticipated that the DIFF stimulus that served as an S- for one outcome and an S+ for a different outcome would transfer to the response trained with the SAME S-. Unfortunately, the high baseline levels of responding (18.9 responses per minute) in the first test prevented detection of significant elevation by that S- (22.0 responses per minute). However, the results of the second test administered following a period of extinction with that response were more encouraging. In the second test, the DIFF S- showed significant transfer. The mean rate of responding increased from 5.6 responses per minute during the ITI to 8.8 responses per minute during the DIFF S- [$T(16) = 26$, $p < .05$]. This result provides some verification that S+ training was adequate to allow the stimulus to encode the identity of the outcome earned in its presence and provides a replication of the transfer effect reported by Colwill and Rescorla (1988). Finally, consistent with previous findings, the stimulus established first as an S- and then as an S+ for the same outcome did not transfer to the response trained with a different outcome in either test. The mean rates of responding dur-

ing the SAME S- were 24.3 and 5.4 responses per minute in the first and second tests, respectively. Neither of these rates was significantly different from the ITI baselines, 20.8 and 5.4 responses per minute in the first and second tests, respectively.

In summary, the results of Experiment 2 suggest that an S- provides two types of information. First, an S- signals the identity of the outcome that is omitted; second, an S- instructs the animal not to perform the response used to train that S-. Experiment 3 provides further support for these conclusions.

EXPERIMENT 3

The present study was designed to address two issues. First, it was designed to extend the findings of the previous two experiments that a signal for the omission of a response-contingent outcome suppresses another response trained with the same outcome. Whereas the previous experiments used the selective suppression or retardation of positive discriminative control to index knowledge that a specific outcome was to be omitted, Experiment 3 arranged circumstances in which the selective enhancement of an instrumental response would reveal such knowledge. It has been shown elsewhere that performance of a response that leads to two outcomes, one valued and one negative, is depressed compared with another response trained only with the valued outcome (Meachum, 1990). Consequently, one might expect that presentation of a stimulus trained to predict the omission of the negative outcome might remove the depression reported by Meachum (1990) and lead to an elevation of responding. In contrast, a stimulus that signaled the omission of the valued outcome might lead to further suppression of such a response. The second purpose of Experiment 3 was to examine further the notion that an S- depresses its original response through an inhibitory association. An implication of this account is that the consequences of that response would have little impact on the amount of suppression produced by the S-. Thus, if the response used to train an S- were given two consequences, one valued and one negative, it should still be suppressed by its S- regardless of whether that S- signaled the omission of the valued or negative outcome.

The basic design of this experiment is displayed in Figure 5. Rats were given the same initial training as animals in Experiments 1 and 2. Thus, two stimuli were estab-

lished as signals for the nonreinforcement of an instrumental response. One stimulus (S1) signaled that R1 would not be followed by O1, and the other stimulus (S2) signaled that R2 would not be followed by O2. Then a new response (R3) was trained with both O1 and O2. Following this, one of the outcomes was made aversive. Finally, R3 was tested in the presence of S1 and S2. It was expected that R3 would be elevated by the stimulus that signaled the omission of the devalued outcome and depressed by the stimulus that signaled the omission of the valued outcome. Following this test, the original response whose outcome had been devalued was reinforced with the other valued outcome. That response was then tested in the presence of its original S-. The question was whether performance of that response would be depressed because of the inhibitory S-R association or elevated because of the increase in value of the response consequences resulting from the predicted omission of the devalued outcome.

Method

Subjects and Apparatus. The subjects were 16 experimentally naive Holtzman-derived Sprague-Dawley male rats (Harlan Co.) about 100 days old at the start of the experiment. Conditions of housing and maintenance were the same as those described in Experiment 1. The apparatus was the same as that used in Experiment 2.

Procedure. The procedure for magazine training was the same as that described for Experiment 2. Following magazine training, all animals were trained to make two responses, nose poke and handle pull, for two different reinforcers, pellets and sucrose. For half the animals, nose poking produced pellets and handle pulling produced sucrose; for the remaining animals, the opposite response-outcome combinations were arranged. Initial training was identical to that described in Experiment 2.

S- training. The details of this training phase were the same as those described for Experiments 1 and 2 except that there were only 10 initial sessions of training with each S- stimulus. Three additional sessions of training with each S- were administered following training of the transfer response.

Transfer training. For all animals, leverpressing was trained with both pellet and sucrose outcomes. In the first session of CRF training, pellets served as the reinforcer; in the second session, sucrose served as the reinforcer. These sessions terminated after 25 reinforcers had been earned. Then responding was reinforced with both pellets and sucrose. The reinforcers were delivered on independent VI 60-sec schedules with the constraint that a reinforcer of one type could not be set up if a reinforcer of the other type were already set up. There were four 20-min sessions of this training.

Devaluation. There were six 2-day cycles of reinforcer devaluation. On the first day of each cycle, the to-be-devalued reinforcer was delivered on a VT 60-sec schedule either until 5 reinforcers had collected in the food magazine or until 20 reinforcers had been

S- training	Transfer	Devaluation	Test 1	Retrain	Test 3
R1->O1, S1: R1->O1	R3->O1+O2	O1+, O2-	S1: R3	R1->O2	S1: R1 S2: R1
R2->O2, S2: R2->O2		O2+, O1-	S2: R3	R2->O1	S1: R2 S2: R2

Figure 5. Basic design of Experiment 3. R1, R2, and R3 are instrumental responses (nose poking, handle pulling, and leverpressing); S1 and S2 are negative discriminative stimuli (noise and light); O1 and O2 are reinforcers (sucrose and pellets); + and - indicate devalued or not devalued.

delivered and eaten. When the session terminated, the animal was removed from the operant chamber, given a 5 ml/kg intraperitoneal injection of .6M lithium chloride (LiCl), and returned to the home cage. On the second day of each cycle, the other reinforcer was delivered on a VT 60-sec schedule for 20 min. The animals were returned to their home cage immediately after this session terminated. On the last three devaluation cycles, the doors of the sound-attenuating chambers were open to permit observation of reinforcer consumption.

The effectiveness of the conditioning treatment was assessed in a consumption test administered after the second S- test. The consumption test contained a single presentation of a reinforcer. Two minutes after delivery of that reinforcer, the subject was removed from the chamber and whether or not the reinforcer had been eaten was recorded. The pellet reinforcer was tested first, and then the test was repeated with the sucrose reinforcer.

S- testing. There were three tests of the S- stimuli. Each test consisted of eight 30-sec presentations each of the noise and light S- with an ITI of 30 sec. The order of stimulus presentations followed a double alternating sequence. In the first test, the lever was available; in the second test, the nose-poke and handle-pull responses were available; and in the final test, the response (nose poke or handle pull) trained with the devalued outcome was available. Responding was never reinforced in the test sessions. Immediately preceding the final test, subjects were given one session of training with the response used in that test. Responding was reinforced with the currently valued reinforcer on a VI 30-sec schedule for 20 min.

Results and Discussion

Over the course of S- training, both stimuli acquired good inhibitory control over their respective responses. In the final session of training, collapsed across stimulus, response, and reinforcer identity, the mean rate of responding in the absence of the stimuli (30.7 responses per minute) was considerably higher than the mean rate of responding in their presence (10.8 responses per minute) [$T(16) = 0, p < .01$]. The degree of discriminative control was not affected by the identity of the stimuli, responses, or reinforcers.

Training of the transfer response proceeded smoothly. In the final session of simple VI training, the mean rate of leverpressing was 17.6 responses per minute.

The results of the transfer test with the lever are shown in Figure 6. At the beginning of testing, the rate of leverpressing relative to the ITI baseline increased when the stimulus signaling the omission of the devalued reinforcer was presented (filled circles). Analysis of the first test trial revealed that difference to be significant [$T(14) = 20.5, p < .05$]. In contrast, that response was depressed, though not significantly, by presentation of the stimulus signaling the omission of the currently positive outcome (open circles). Direct comparison of the response rates in the presence of these two stimuli found the difference to be significant on the first test trial [$T(14) = 17, p < .05$]. However, all of these differences disappeared over the course of testing as responding rapidly extinguished.

The results of this test provide further evidence for encoding of the identity of the omitted reinforcer by an S-. Responding that had been trained with two outcomes, one of which was subsequently devalued, increased in the presence of a stimulus that had previously signaled the omis-

Figure 6. Mean responses per minute during the transfer test with the lever response in Experiment 3 (Test 1). Responding is shown during the S- that signaled omission of the devalued outcome (filled circles), during the S- that signaled omission of the valued outcome (open circles), and during the ITI (dashed line).

sion of the devalued reinforcer for a different response. A stimulus trained to signal the omission of the valued reinforcer had the opposite effect on this response. The specificity of the enhancement indicates that a stimulus does provide information about the identity of response-contingent outcomes that are omitted in its presence.

The S- were tested with their original responses to verify the effectiveness of the devaluation procedure and to evaluate the specificity of discrimination training. The results of that test with the nose-poke and handle-pull responses and S- stimuli are displayed in Figure 7. Responding is plotted in blocks of two trials and separated as a function of whether the outcome used to train that response was devalued (left panel) or not (right panel). Inspection of responding during the ITI (dashed lines) shows quite clearly that, despite a general decline in responding over testing, performance of the response trained with the currently devalued reinforcer was substantially lower than responding trained with the currently valued outcome [$T(16) = 18, p < .05$]. This result indicates the success of the devaluation manipulation and replicates earlier studies showing the sensitivity of instrumental responses to a change in the value of an outcome that they had previously earned (e.g., Adams & Dickinson, 1981; Colwill & Rescorla, 1985).

When tested with the response originally used to train the S- (filled circles), the S- suppressed its response regardless of the current value of the outcome for that response. Relative to the ITI baseline rate, responding trained with the outcome that had been devalued was depressed by its S- [$T(12) = 8, p < .05$], as was responding trained with the unaltered reinforcer [$T(15) = 3, p < .05$]. Examination of these responses when they were tested in transfer with the S- trained with the other response-outcome combination (open circles) revealed only a marginal and nonsignificant reduction in the rate

of responding relative to the ITI rates in both cases. These results indicate that the S-s suppressed the responses with which they had been trained and with which they shared an outcome. This finding is consistent with the view that S-s encode information about the identity of the omitted outcome. But it is also consistent with the view that S-s encode information about the responses whose nonreinforcement they signal. The results of the final test bear on this issue.

In the final test, the response whose original outcome had been devalued was retrained with the other valued outcome and then presented with its original S-. If S-s control their own responses in the same way that they control transfer responses, then the S- should now elevate its own response just as it had elevated the transfer response in the first test. However, if the S- controls its own response through an inhibitory S-R association, then it should continue to suppress its response. The results of the final test are shown in Figure 8. Subsequent training with the valued reinforcer was successful in elevating the level of the devalued response as shown by the high rate of responding during the ITI (dashed line). That this training was adequate to establish an association between that response and the valued outcome is supported by the ability of the S- that signaled the omission of the valued outcome to depress that response (open circles). Although an overall analysis failed to find evidence of significant suppression [$T(16) = 35.5, p > .05$], responding was lower in the presence of this signal compared with the ITI on the second block of test trials [$T(14) = 11, p < .05$]. Presentations of the S- that signaled the omission of the devalued outcome (filled circles) almost completely eliminated responding [$T(16) = 0, p < .01$]. This finding is opposite in direction to that reported in the trans-

Figure 8. Mean responses per minute in blocks of two trials during the test in Experiment 3 with the response whose original outcome was devalued (Test 3). Responding is shown in the presence of the S- originally trained with that response (filled circles), in the presence of the S- trained with a different response (open circles), and during the ITI (dashed line).

fer test with the lever and suggests that the S- develops a strong inhibitory association with the instrumental response that is nonreinforced in its presence.

These results further demonstrate that S-s will transfer to responses trained with the same outcome whose omission they predict. However, the present data also suggest that an additional association between the S- and the instrumental response is important in controlling performance of the original response. These conclusions about the associative structure of S-s parallel those drawn by Colwill and Rescorla (1986) for S+s.

GENERAL DISCUSSION

These experiments provide clear evidence that the animal encodes information about the relation between a stimulus and a response-contingent outcome that is omitted in the presence of that stimulus. Experiment 1 showed that a stimulus that signaled the nonreinforcement of a response would selectively depress another instrumental response trained with the same outcome. Experiment 2 examined the speed with which an S- became an S+ for a new instrumental response as a function of outcome identity. When that response earned an outcome that was the same as the one whose omission had been predicted by the S-, acquisition of positive discriminative control was retarded. Experiment 3 found that a response trained with two outcomes, one of which was subsequently devalued, increased in rate in the presence of an S- that signaled the omission of the devalued outcome. These effects are consistent with the thesis that signals for the nonreinforcement of instrumental responses provide information about the identity of the omitted outcomes.

The identification of a reinforcer-specific component of S-s is embarrassing to two classes of traditional ac-

Figure 7. Mean responses per minute in blocks of two trials during the test of the S-s with the responses used to train them in Experiment 3 (Test 2). Responding is separated according to whether the outcome had been devalued (left panel) or not (right panel). Within each panel, responding is shown during the ITI (dashed line), during the S- originally trained with that response (filled circles), and during the S- trained with a different response (open circles).

counts of S- control. On the one hand, it forces rejection of theories that claim an S- is indistinguishable from a neutral cue (Capaldi, 1970; Thorndike, 1911). Typically, such accounts argue that the S- does not evoke the instrumental response because it lacks an association with that response. On the other hand, the outcome specificity of S-s creates problems for response competition theories (Guthrie, 1935; Hull, 1943; Thorndike, 1932). According to this position, the S- suppresses instrumental responding by virtue of its ability to elicit an incompatible response. In neither case is it anticipated that an S- will transfer differentially to other responses depending on the identity of the outcomes used to establish them.

The present data also have important implications for evaluating more recent accounts of S- control that invoke Pavlovian conditioned inhibition to explain the suppressive effects of S-s. This position has been discussed in some detail by Rescorla and Solomon (1967) and by Rilling (1977). According to this view, S-s are assumed to have the same properties as Pavlovian conditioned inhibitors. This idea seems plausible given the procedural similarities between S- training and Pavlovian conditioned-inhibition training: both involve the presentation of a stimulus at a time when an expected outcome is withheld. However, there is little consensus about the details of how Pavlovian conditioned inhibitors act. Two primary accounts have emerged, one arguing that inhibitors depress activation of the representation of the outcome and the other that they reduce the motivational support for performance. The finding of outcome specificity is useful for discriminating between these accounts since the former anticipates specificity whereas the latter does not.

The position that Pavlovian conditioned inhibitors reduce the motivation for responding has been championed by Dickinson and his colleagues (Dickinson, 1980; Dickinson & Dearing, 1979; Dickinson & Pearce, 1977). Specifically, they have argued that stimuli signaling the omission of rewarding outcomes activate an aversive central motivational system, which in turn inhibits an appetitive central motivational system. By reducing the output of the latter, appetitively motivated behavior is depressed. According to this view, the effect of a signal for the omission of pellets is indiscriminable from that of a signal for the omission of sucrose. Claims that Pavlovian inhibitors transfer across signals trained with different outcomes belonging to the same motivational class have been used to support this position (Nieto, 1984; Pearce, Montgomery, & Dickinson, 1981). The present findings of outcome-dependent transfer are rather awkward for this point of view. It is unlikely that there are separate motivational systems underlying responding for pellets and responding for sucrose that are selectively inhibited by the appropriate S-s. Such a view is at odds with prevailing theories of motivation. Moreover, it is difficult to reconcile an approach that assumes multiple motivational systems with the empirical evidence that prompted a dual motivational approach and encouraged claims about the motivational equivalence of affectively similar events. For these

reasons, the present findings are also troublesome for Amstel's frustration theory (Amstel, 1962). He has argued that the omission of an expected reward generates a general state of frustration that is conditioned to the S-. On subsequent presentations of the S-, this aversive state is activated, one consequence of which is to reduce the motivation for making the target instrumental response. Thus, this view makes the incorrect prediction that an S- should transfer nondifferentially across instrumental responses trained with different rewards. The present studies were not directed to the issue of whether there is any transfer of an S- trained with one outcome to responses trained with physically different but affectively similar outcomes. Such transfer is precisely the kind that the motivational perspective can explain. But the selectivity observed in these experiments requires a somewhat different explanatory framework.

The idea that inhibitors act on the outcome representation appears to provide a graceful account for the selective transfer obtained in the present experiments. Essentially, inhibitors are thought to alter activation of the representation of the outcome whose omission they predict. Responding is then depressed because the excitator is less effective at activating the outcome representation. This position was developed by Konorski (1948) and has been persuasively defended by Rescorla and Holland (1976). However, there is surprisingly little evidence for the obvious prediction that Pavlovian inhibitors should have some reinforcer specificity (Kruse, Overmier, Konz, & Rokke, 1983). Kruse et al. (1983) found evidence of reinforcer specificity when they tested inhibitors for their ability to modulate the effects of an S+ on its instrumental response. The inhibitor slowed completion of the ratio requirement when it signaled omission of the outcome earned by that response, but not if it signaled the omission of a different outcome. However, when presented without the S+, the inhibitors did not influence choice of instrumental responses. Thus, some of the difficulty in detecting reinforcer-specific effects of Pavlovian inhibitors may be attributable to the use of targets that may not be especially receptive to transfer.

The view that instrumental discriminative stimuli might modulate activation of the outcome representation was discussed at length by Colwill and Rescorla (1988). It is an attractive idea for two reasons. First, it offers a simple explanation for the ability of S+s and S-s to transfer to responses trained with the same outcome. Second, it provides a cohesive structure for describing instrumental discriminative stimuli, which specify response-outcome relations, and their Pavlovian counterparts, facilitators and inhibitors, which specify stimulus-outcome relations. That the symmetry in the procedures used to establish S+s and facilitators might force similar associative structures is supported by the observation that facilitators can substitute for S+s in augmenting instrumental behaviors (Davidson, Aparicio, & Rescorla, 1988). Unfortunately, analogous comparisons of S-s and inhibitors are lacking. However, other comparisons that have been made

between Pavlovian inhibitors and negative discriminative stimuli have failed to produce results congenial to a view that embraces S-s and conditioned inhibitors in a common associative framework (Bonardi, 1988).

Although the modulatory view has some merit in its ability to handle the outcome-specificity effects reported here, it does not provide a complete account of the associative structure of S-s. The results of Experiments 2 and 3 also suggest that S- control involves an additional associative connection between the S- and the original response. In Experiment 2, an S- continued to suppress its original response even though it had been trained to signal the availability of that outcome for another response. Moreover, the degree of suppression was indistinguishable from that exerted by an S- established as an S+ for a different response-outcome relation. In Experiment 3, an S- was tested with its original response following devaluation of the outcome used to train that response. Not surprisingly, the S- suppressed its original response. The unusual finding, however, was that the S- continued to suppress this response even after the response had been trained with another valued outcome. These observations suggest that S- training establishes an inhibitory association between the S- and its instrumental response.

The idea that S-R associations might contribute to instrumental performance has been discussed by several authors (Colwill & Rescorla, 1986; Mackintosh, 1983; Mackintosh & Dickinson, 1979). Mackintosh (1983), for instance, argued that such a mechanism is needed to solve certain kinds of conditional discriminations. However, although it has been relatively difficult to obtain direct evidence for S-R associations in positive instrumental discriminations, the present result suggests that it may be more fruitful to analyze their characteristics by studying the properties of an S-. Furthermore, this finding has important implications for attempts to compare S-s and Pavlovian inhibitors (e.g., Bonardi, 1988). Even if both modulate the outcome representation, an S- will always show superior transfer to an instrumental response because the original inhibitory S-R association will provide a source of generalization for the S- that is unavailable for the Pavlovian inhibitor.

Finally, it is important to acknowledge an alternative framework that has recently been proposed by Bonardi (1989) and by Colwill and Rescorla (1990) for understanding instrumental discriminative stimuli. This view attempts to represent the three-term contingency in the learning structure by allowing the S+ to activate the response-outcome relation. This kind of relational account is able to accommodate several experimental results that are problematical for the types of dyadic associative structures mentioned above. Especially strong evidence favoring the view that S+s encode relational information comes from a study by Colwill and Rescorla (1990) in which two S+s were trained with two responses and two outcomes. Each S+ signaled the same individual elements, but the responses and outcomes were combined in differ-

ent ways so that one S+ uniquely signaled one pair of response-outcome relations and the other S+ uniquely signaled the other pair of response-outcome relations. Then one of the outcomes was devalued, and the two S+s were tested with the responses. Performance in the presence of the S+s was conditional upon their identity and appropriate to the value of the outcome signaled by the S+ for that response. Because the dyadic relations were identical, the S+s could only have controlled the preference for a response in this way if they provided relational information about the responses and their outcomes.

It is possible to accommodate the present results within a relational account of discriminative instrumental learning. Colwill and Rescorla (1990) have discussed how the transfer effect may be derived by invoking a principle of generalization. In essence, transfer of an S+ is assumed to be the consequence of greater generalization to new responses based on shared association with a common outcome. A similar argument may be made to deal with the transfer of S-s demonstrated in the experiments reported here. To explain the finding of continued suppression by an S- of its original response, it would have to be argued that the test simply reinstates the conditions of training. Thus, the animal does what it has learned to do in the presence of the S-. This argument also makes the reasonable assumption that the relational structure established by S- training is not affected by subsequent reinforcement of the instrumental response with some other outcome.

In conclusion, the present findings are suggestive of two important similarities between S+s and S-s. In both cases, there appears to be an association between the stimulus and the outcome and between the stimulus and the response. It will be of interest to explore the parallel further by examining whether an S- also provides information about particular response-outcome relations arranged in its presence.

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