Inhibitory discriminative control is specific to both the response and the reinforcer

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Inhibitory Discriminative Control
Is Specific to Both the Response
and the Reinforcer
Charlotte Bonardi
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In two experiments an S delta was established which signalled the absence of an instrumental contingency between a particular response, R1, and a particular reinforcer, Rf1. The S delta suppressed operant responding, and the specificity of this suppression to the elements of the response–reinforcer association, R1 and Rf1, was explored. Experiment 1 showed that the S delta suppressed performance of R1 more effectively than it suppressed performance of a second response, R2. Experiment 2 showed that the S delta suppressed performance of a response rewarded with Rf1 more effectively than it suppressed performance of a response that had been rewarded with a second reinforcer, Rf2. These results suggest that an S delta’s suppressive effects are specific to the particular response and reinforcer, which were uncorrelated in its presence during training. The implications of these results for theories of inhibitory discriminative control and for theories of occasion setting are discussed.

An S delta may be defined as a signal for the absence of a response–reinforcer correlation. Until recently the suppression of responding produced by such stimuli was implicitly attributed to Pavlovian inhibitory conditioning (Hull, 1943; Rescorla & Solomon, 1967; Trapold & Overmier, 1972). There is now some evidence to suggest, however, that an S delta that suppresses operant responding does not fulfil the criteria for Pavlovian conditioned inhibition, whereas Pavlovian inhibitors fulfilling such criteria appear to be unable to suppress operant responding (Bonardi, 1988a; see also Bonardi, 1988b; Goodall & Mackintosh, 1987). A new account of S-delta function is clearly required. One obvious candidate is suggested by the operational parallel between S deltas and negative occasion setters. An S delta signals that a

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response will be nonreinforced and suppresses performance of that response; a negative occasion setter signals that a Pavlovian conditioned stimulus, or CS+, will be nonreinforced, and suppresses responding to that stimulus. One possible step towards formulating a theory of S-delta function, therefore, is to attempt to apply existing theories of negative occasion setting.

Theories of negative occasion setting may be divided into two categories, which differ primarily in the proposed target of the occasion setter’s action. Holland suggests that a negative occasion setter exerts an inhibitory effect on the CS–US association as a discrete unit; in colloquial terms it signals that the CS–US relation will not hold (e.g. Holland, 1984; Holland, 1985; Holland & Lamarre, 1984; Lamarre & Holland, 1987). In contrast, Rescorla has suggested that negative occasion setters raise the threshold above which the US representation may be activated (e.g. Rescorla, 1985; Rescorla, 1986a; Rescorla, 1986b; Rescorla, 1987). This second suggestion effectively asserts that negative occasion setters are identical to Pavlovian conditioned inhibitors (although there is some evidence against this view—e.g. Holland, 1984; Holland & Gory, 1986; Holland & Lamarre, 1984; Lamarre & Holland, 1987).

These two theories make different predictions about the extent to which the effects of occasion setters will transfer. The first, arguing that the occasion setter acts on a specific CS–US association, predicts that the inhibitory properties of a negative occasion setter should be specific to a particular CS+, and thus that an occasion setter will not suppress the responding elicited by a second CS. The second, arguing that the occasion setter acts on the US representation alone, predicts that a negative occasion setter should be equally able to suppress the responding elicited by any CS+ that is associated with that particular reinforcer, and thus, like Pavlovian inhibitors (Rescorla & Holland, 1977), should show perfect transfer to a second CS.

The aim here is to assess the extent to which these theories of negative occasion setting prove appropriate as accounts of S-delta function. The differing predictions just described provide a means of distinguishing between the two theories in the context of inhibitory discriminative control. If we translate the account developed by Holland into the terms of instrumental conditioning, it would assert that the S delta has an inhibitory effect on the entire response–reinforcer association. It would therefore predict that an S delta that has been established as a signal that response R1 will be nonreinforced should inhibit performance of R1 more effectively than performance of some other transfer response, R2. In contrast, if Rescorla’s theory were applied to the instrumental case, it would assert that the S delta raises the activation threshold of the representation of the reinforcer. This account implies that the S delta should suppress performance of R2 as effectively as it suppresses performance of R1. Experiment 1 was designed to investigate these predictions.
INHIBITORY DISCRIMINATIVE CONTROL

EXPERIMENT 1

Some studies have investigated whether S deltas can inhibit performance of other responses (e.g. Hearst & Peterson, 1973; Gutman & Maier, 1978) and have found that significant suppression of a transfer response may be produced. However, even if the S delta is response-specific, performance of the transfer response might still be suppressed to some extent because of generalization between the two responses. In order to validate the predictions of an account that asserts that the S delta's inhibitory effects are not response-specific, it is necessary to show that inhibition of responding is of the same magnitude regardless of the identity of the response—or, in other words, that transfer is complete. Such an account could only accommodate incomplete transfer by appealing to generalization decrement. To assess the degree to which transfer is complete, the S delta's effect on the two responses must be compared under comparable conditions, something that previous studies have not done. Experiment 1 was designed to circumvent these problems.

Two groups of animals were rewarded for lever-pressing during presentations of two discriminative stimuli, Sd−l and Sd−r. Two levers were available for responding, one on the left-hand side of the chamber and one on the right-hand side, and animals were rewarded for responding on the left lever during Sd−l, and for responding on the right lever during Sd−r. Then two separate S deltas were established, Ll and Lr. Ll, presented in compound with Sd−l, signalled that responding on the left lever would be nonreinforced, whereas Lr, presented in compound with Sd−r, signalled that responding on the right lever would be nonreinforced.

The test phase procedure was designed to investigate the extent to which suppression of responding produced by Ll was specific to the left response and the suppression produced by Lr specific to the right response. The subjects were divided into two groups and were all rewarded for lever-pressing during presentations of Ll and Lr. The groups differed in the response contingencies signalled by these two stimuli. Subjects in Group C (congruent) were rewarded for responding on the left lever during Ll and on the right lever during Lr, so that the “correct” response was on the left during Ll and on the right during Lr. Group I (incongruent) received the opposite discrimination; for them the “correct” response was on the right during Ll and on the left during Lr. The logic behind this procedure ran as follows. In order to acquire the discrimination at all, the animals must display a weak tendency to make both left and right—and thus correct and incorrect—responses. If Ll and Lr have response-specific effects, there will be selective suppression of the left response during Ll and of the right response during Lr. However, in Group C these are the “correct” responses, whereas in Group I these are the incorrect responses. Thus response specificity in Ll and Lr implies poorer performance in Group C than in Group I. If Ll and Lr are
not response-specific, on the other hand, there will be no such selective suppression and consequently no reason to expect any difference in performance between the two groups.

Method

Subjects

The subjects were 16 naive male Hooded Lister rats with a mean free-feeding weight of 328 g (range: 300–360 g). They were reduced to 80% of their free-feeding weights before the start of the experiment and were maintained at this level throughout training by being given a limited amount of food at the end of each session.

Apparatus

The apparatus consisted of four Campden Instruments lever-boxes, modified by the provision of a 60-W, 240-V strip light mounted above the white Perspex ceiling. The front panel contained a central opening to the food tray covered by a Perspex flap door; 45-mg mixed-composition food pellets could be delivered into the food trays of each chamber. Two levers were mounted in each chamber, one on the left-hand side of the magazine flap and one on the right-hand side. Illumination was provided by a 2.8-W 14-V houselight, which was mounted centrally in the front wall. Two visual stimuli were used, light and dark. Dark was provided by turning off the houselight, which was otherwise on all the time the animals were in the chambers. Light was provided by turning on the strip light. Two speakers were mounted on the back wall through which a 83-dB, 7-Hz clicker and an 85-dB white noise could be delivered from a Campden Instruments tone generator and a white noise generator. Masking noise was provided by the operation of the ventilating fans. The apparatus was controlled by BBC microcomputers programmed in a version of BASIC.

Procedure

Preliminary Training. During the first, 30-min session the animals were magazine-trained. The levers were removed from the boxes, and food pellets were delivered at variable intervals with a mean duration of 60 sec.

For the rest of preliminary training and all of preliminary variable ratio (VR) training, sessions were scheduled in duplicate pairs. The left lever was present during one session of each pair and the right lever during the other. Reinforcement was contingent on responding on the available lever; in this way the subjects' experience of responding on the two levers was equated. During the next two sessions animals were consistently reinforced for responding, until a minimum of 75 responses had been made. In the final two
sessions of this stage animals were preexposed to the stimuli. Responding was rewarded according to a variable interval (VI) 30-sec schedule. In each session there were six 20-sec stimulus presentations that were without programmed consequence, separated by a mean intertrial interval (ITI) of 260 sec (range: 200–320 sec). The clicker, the noise, light, and dark were each presented once in each session, as were two compound stimuli. For half the animals these compound stimuli were clicker + light and noise + dark, whereas for the remaining animals they were clicker + dark and noise + light. Subjects continued to receive the same compound stimulus combinations during discrimination training.

*Preliminary VR Training.* In this stage animals were trained to respond for reinforcement delivered according to a discrete-trial VR schedule. Half the animals were rewarded for responding on the left lever during the clicker and on the right lever during the noise, whereas the remainder were rewarded for responding on the right lever during the clicker and on the left lever during the noise. The stimulus that signalled that responding on the left lever would be reinforced will be called Sd–l, and that which signalled that responding on the right lever would be reinforced will be called Sd–r. During each of the first eight sessions of this stage there were twelve 20-sec presentations of the Sd that was appropriate to the available lever, during which responding was rewarded according to a VR 2 schedule. The ITI was 11 sec in Sessions 1 and 2, 21 sec in Sessions 3 and 4, and 41 sec in Sessions 5 and 6.

In Sessions 7 and 8 the ITI was of variable duration with a mean of 80 sec (range: 50–110 sec). In addition to the ITI, there was a 20-sec pre-trial period immediately preceding the 20-sec trial. These durations of ITI, pre-trial period, and trial were maintained for the rest of the experiment. This stage was completed with a series of sessions identical to Sessions 7 and 8 except for the value of the VR schedule. There were four sessions with a VR 3 schedule, then two with a VR 4 schedule, two with a VR 5 schedule, and finally four with a VR 6 schedule.

*Discrimination Training.* For the rest of the experiment both left and right levers were always present. Responding was still rewarded only if it occurred during presentations of the appropriate Sd, but responding on both levers was recorded. In the first eight sessions of this stage there were 24 trials, 12 presentations of Sd–l and 12 of Sd–r, intermixed in a semi-random order. The schedule was VR 4 in Session 1, VR 5 in Session 2, and VR 6 in the remainder.

In the next twelve sessions two further types of trial were introduced. In each of these sessions there were nine presentations of Sd–l and nine of Sd–r, during which response-contingent reinforcement was available according to
a VR 6 schedule as before. In addition there were three presentations of each Sd in compound with one of the visual stimuli, light and dark; no reinforcers were ever delivered during these Sd/L compound stimulus presentations. Light and dark were counterbalanced across type of discriminative stimulus (clicker or noise) and type of response (left or right). The stimulus presented in compound with Sd–l will be called Ll, and that in compound with Sd–r, Lr.

Test. At this point the subjects were divided into two groups of eight subjects. In each session there were 12 presentations of Ll and 12 of Lr, intermixed in a semi-random order, and response-contingent reinforcement was available during these stimulus presentations. The groups differed in the nature of the response–reinforcer contingencies signalled by the stimuli. In the first eight sessions of this stage animals in Group C were rewarded for responding on the left lever during Ll and on the right lever during Lr—a "difficult" discrimination, as it contradicted the reinforcement contingencies imposed during discrimination training. Subjects in Group I were trained on the opposite and therefore "easy" discrimination: these animals were rewarded for responding on the right lever during Ll and on the left lever during Lr. The reinforcement schedule was VR 6 in the first session and VR 3 in the remaining sessions. Then there were two sessions of extinction, identical to the preceding sessions except that no reinforcers were delivered. Finally there was a second acquisition phase, in which each group was trained on the reverse discrimination. Thus Group C was shifted from the "difficult" to the "easy" discrimination and received reward for responding on the right lever during Ll and on the left lever during Lr. Group I was shifted from the "easy" to the "difficult" discrimination and received reward for responding on the left during Ll and on the right during Lr. There were eight sessions in this second acquisition phase.

Results

In all analyses reported below a significance level of \( p < 0.05 \) was adopted. In order to correct for individual differences in baseline responding, the number of responses made during each pre-trial period was subtracted from the number of responses made during each trial to obtain a "corrected" score for that trial. Response rates to a given stimulus were calculated by pooling the corrected scores for all trials of that type in a session.

**Discrimination Training.** The corrected response rates for the last session of discrimination training are shown in the top panel of Table 1. The scores are presented separately for responding on the correct and on the incorrect lever during Sd and Sd/L trials. The correct lever during Sd/L
TABLE 1
Group Mean Response Rates for Sd and Sd/L Trials During the Last Discrimination Training Session of Experiment 1

<table>
<thead>
<tr>
<th>Response Rates</th>
<th>Sd</th>
<th>Sd/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct Lever</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect Lever</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During trials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group C</td>
<td>47.33</td>
<td>-1.03</td>
</tr>
<tr>
<td>Group I</td>
<td>49.39</td>
<td>-0.37</td>
</tr>
<tr>
<td>During pre-trial periods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group C</td>
<td>1.81</td>
<td>1.40</td>
</tr>
<tr>
<td>Group I</td>
<td>1.29</td>
<td>1.44</td>
</tr>
</tbody>
</table>

Response rates = responses per minute.

compound trials was taken to be the lever that was correct during the Sd alone. Subjects in both groups responded substantially more during the Sd alone than during Sd/L compound trials, and substantially more on the correct lever than on the incorrect. An analysis of variance was performed on these data with Group (C or I), Trial (Sd or Sd/L compound) and Lever (correct or incorrect) as factors. This revealed a main effect of Trial, $F(1, 14) = 39.64$, of Lever, $F(1, 14) = 69.37$, and a significant interaction between these two factors, $F(1, 14) = 40.38$. The interaction reflected the fact that response rates on the correct lever were high during Sd trials and low during Sd/L trials, whereas rates on the incorrect lever were low during both types of trial. No other effects or interactions were significant ($Fs < 1$). The bottom panel of Table 1 shows the pre-trial response rates during this session; these did not appear to differ among the various types of trial. This impression was confirmed by an analysis of variance with Group (C or I), Lever (correct or incorrect), and Trial (Sd and Sd/L compound) as factors, which revealed no significant effects or interactions [largest $F(1, 14) = 3.65$].

Test. The results of the test sessions are shown in Figure 1. The score used was a choice measure. During each session there were 24 trials, on each of which the animal had to choose a lever on which to respond first. Some of these first choices would be correct and some incorrect. The total number of
incorrect choices each subject made in a session was subtracted from the total number of correct choices, to produce a difference score; the greater the difference score, the better the discrimination. Difference scores, averaged over sessions, are presented separately for the initial acquisition phase and the second, reversal phase. In the first phase Group C, trained on the "difficult" discrimination, performed less efficiently than Group I, while in the second reversal phase Group C, now being trained on the "easy" discrimination, performed more efficiently than Group I. An analysis of variance performed on these data with Group (C or I) and Phase (initial or reversal) as factors revealed no main effect of group ($F < 1$) or phase [$F(1, 14) = 2.53$], but a significant Group × Phase interaction, $F(1, 14) = 4.65$. The difference between the groups was not quite significant in the first phase ($t = 1.39$) but was statistically significant in the second, $t = 2.30$.

Discussion

In the training phase of this experiment stimulus L1 signalled that responding on the left lever would be nonreinforced, and stimulus Lr signalled that responding on the right lever would be nonreinforced. Subsequently animals in Group C learned to respond on the left lever during L1 and on the right lever during Lr more slowly than animals in Group I, who had to learn to respond on the right lever during L1 and on the left lever during Lr. When both groups were switched to the reversal, Group C, originally less efficient than Group I, became more efficient.

These results imply that the initial training had produced S deltas having inhibitory properties specific to the response whose nonreinforcement they had signalled during training. This finding cannot be explained by an account of S-delta function which asserts that an S delta's inhibitory effects are not response-specific. Such an account might perhaps be able to accommodate
the occurrence of incomplete transfer by arguing that the change of conditions between training and test generates more generalization decrement in Group I than in Group C. But it is difficult to construct a compelling argument in these terms; one possibility is that for Group I a given S delta acquires inhibitory properties while the subject is responding on the left lever (say), and that the test schedule makes it more likely that these subjects will experience the S delta while responding on the right lever. If the stimulus is perceived differently from the different locations, generalization decrement might result. Such a hypothesis would be hard to assess, but it is rendered less plausible by the fact that at the end of training subjects were responding on neither lever during the S delta and so were unlikely at this stage to be experiencing the stimulus from a consistent position in the box.

If we may conclude that S deltas have response-specific effects, this result would have several implications. First, suppose we wish to use a theory of occasion setting to account for S-delta function. The absence of transfer across responses is consistent with an instrumental adaptation of Holland's theory and suggests that this account might provide an appropriate explanation of S-delta function. It is not, on the other hand, consistent with the instrumental version of Rescorla's account of negative occasion setters—and this is perhaps not surprising. Rescorla's account of occasion setting asserts that the S-delta functions by virtue of Pavlovian inhibition, so that when it is applied to the instrumental case it becomes formally equivalent to the traditional explanations of inhibitory discriminative control. As we have seen, these explanations can be rejected on empirical grounds (Bonardi, 1988a, Goodall & Mackintosh, 1987).

Finally, if S deltas are indeed a type of occasion setter, the results of this experiment imply that negative occasion setters should also not be specific to the CS. To recap, if a negative occasion setter is CS-specific, it should be less effective at suppressing responding to a transfer excitor than to its original excitor, whereas if there is no CS specificity, there should be no more responding when the inhibitor is presented with the transfer excitor than when it is presented with its original excitor. Finding a difference on this comparison therefore suggests that the effects of such stimuli are CS-specific. Those published results that allow such a comparison show that negative occasion setters are invariably less effective at suppressing responding to a transfer excitor than to the original excitor (e.g. Jenkins, 1985; Holland & Lamarre, 1984; Lamarre & Holland, 1987; Rescorla, 1985), and in the one case where appropriate statistics were reported, this difference attained statistical significance (Lamarre & Holland, 1987). This suggests that, consistent with the results of the present experiment, negative occasion setters appear to be CS-specific.

However, there is some dispute in the literature over this issue: Jenkins argues that negative occasion setters are CS-specific, Holland and Lamarre
that they sometimes show CS specificity, whereas Rescorla denies any specificity at all. This confusion seems to arise because significant suppression of responding to a transfer CS, rather than the absence of a difference between original and transfer CS suppression, is typically taken as evidence of transfer across CSs (e.g. Holland & Lamarre, 1984; Rescorla, 1985). It is not clear, however, that such suppression is adequate to rule out CS-specificity, as this result could easily be obtained simply by means of generalization between the original and transfer excitors. One might therefore expect that such "pseudotransfer" will not occur consistently but will be more likely in experiments where generalization between original and transfer excitors is favoured. In support of this assertion, significant "pseudotransfer" to the same type of transfer excitor is, indeed, inconsistently obtained (e.g. Holland & Lamarre, 1984; Lamarre & Holland, 1987). Moreover, there is some indication that reducing the similarity of original and transfer excitors does reduce the amount of suppression to the transfer CS. For example, Rescorla (1985) reported good suppression of responding to a transfer excitor in pigeons when the original and transfer excitors were a white key and a black X on a white background (see Holland & Lamarre, 1984), but this suppression was substantially reduced in a second experiment when the two excitors were changed to red and horizontal. Similarly, in Lamarre and Holland's (1987) third experiment animals were trained on pairs of discriminations with excitors that were either in the same or in different modalities. Again, transfer was substantially reduced when the two excitors were in different modalities relative to when they were in the same modality.

EXPERIMENT 2

The results of the first experiment are consistent with the possibility that Holland's account of negative occasion setting could provide an adequate account of discriminative inhibitory control. The instrumental version of this hypothesis would assert that the S delta signals that a specific response--reinforcer relation does not hold, thus allowing the inhibitory effect of an S delta to be specific to a particular response. Holland's account of occasion setting also predicts that the inhibitory effect of a negative occasion setter will be specific to a particular reinforcer. In this respect it accords with Rescorla's proposal that negative occasion setters alter the activation threshold of the US representation.

In support of this prediction, Holland (1985) reported that an occasion setter predicting the nonreinforcement of a CS that signalled shock could not counteract the responding elicited when that same CS was converted into a signal for food. If a theory of occasion setting is to account for the properties of an S delta, the suppressive effects of such stimuli should also be reinforcer-
specific. In other words, if during training an $S$ delta signals that a response will no longer be followed by reinforcer $R_f$, then it should be better able to suppress performance of a response that has been paired with that same reinforcer, $R_f$, than with some other reinforcer, $R_f$. Experiment 2 was designed to investigate this prediction.

Two groups of animals were rewarded for lever-pressing during presentations of two discriminative stimuli, $S_d$ and $S_d$. They were rewarded with food pellets during presentations of $S_d$, and with sucrose pellets during presentations of $S_d$. Then two separate $S$ deltas were established, $L_f$ and $L_s$. When $S_d$ was presented in compound with $L_f$, or $S_d$ in compound with $L_s$, responding was never rewarded. Operationally, $L_f$ signalled that responding would no longer be rewarded with food, whereas $L_s$ signalled that responding would no longer be rewarded with sucrose. The test phase was designed to establish the extent to which the animals had learned these reinforcer-specific rules. The animals were divided into two groups and were rewarded for lever-pressing during presentations of $L_f$ and $L_s$. The groups differed in the reinforcement contingencies that accompanied these stimulus presentations. Subjects in Group $C$ (congruent) were rewarded with food during presentations of $L_f$ and with sucrose during presentations of $L_s$. Subjects in Group $I$ (incongruent) received the reverse discrimination and were rewarded with sucrose during $L_f$ and with food during $L_s$. If the effects of $L_f$ and $L_s$ are reinforcer-specific, food-rewarded responding should be suppressed during $L_f$, and sucrose rewarded responding should be suppressed during $L_s$. Thus in Group $C$ the appropriate responses would be suppressed during stimulus presentations, whereas in Group $I$ they would not. Thus reinforcer-specificity would predict poorer performance in Group $C$ than in Group $I$. If, on the other hand, the effects of $L_f$ and $L_s$ are not reinforcer-specific, there are no grounds for expecting any difference in the rate of acquisition in the two groups.

Method

Subjects

The subjects were 16 naive male Hooded Lister rats with a mean free-feeding weight of 388 g (range: 360–410 g). They were maintained exactly as in Experiment 1.

Apparatus

The apparatus consisted of two Campden Instruments lever-boxes, which were identical to those used in Experiment 1 except in the following respects: They were each equipped with two pellet dispensers, one of which delivered 45-mg mixed-composition food pellets and the other of which delivered 45-mg sucrose pellets, both into the same food tray. A single rat lever was
mounted on the right-hand side of the magazine opening. Illumination was provided by a 2.8-W 14-V houselight mounted in the middle of the ceiling. Two visual stimuli were used, light and dark. Dark was provided by turning off the houselight, which was otherwise on all the time the animals were in the chambers. Light was provided by turning on the three 2.8-W 24-V house-lights situated above and to the left and right of the magazine. A loudspeaker was mounted in the ceiling, from which a 80-dB 7-Hz clicker and a 85-dB white noise could be delivered from a Campden Instruments tone generator and a white noise generator.

Procedure

Preliminary Training. During the first, 30-min, session the animals were magazine-trained. The levers were removed from the boxes, and two pellets, one food and one sucrose, were delivered simultaneously at variable intervals with a mean of 60 sec.

The levers were then returned to the chambers, and sessions were commenced during which reinforcers were delivered contingent upon lever-pressing. During the rest of preliminary training, and all of the subsequent preliminary VR training stage, animals only received one type of reinforcement, food or sucrose, in a session. In order to equate subjects' experience with each of these reinforcers, all animals received each session in duplicate; in one of each pair responding was rewarded with food and in the other with sucrose.

During the next pair of sessions each subject was consistently reinforced for lever pressing until it had earned at least 75 pellets. During the next pair of sessions, which were each of approximately 30-min duration, the animals were preexposed to the stimuli exactly as in Experiment 1.

Preliminary VR Training. At this point sessions were introduced during which animals were rewarded for lever-pressing according to a discrete trial VR schedule during presentations of the clicker and of the noise. One stimulus, Sd–f, signalled response-contingent food, while a second, Sd–s, signalled response-contingent sucrose. Each session contained only one of the two auditory discriminative stimuli, which were counterbalanced across reinforcer type. In the first two sessions there were 36 20-sec stimulus presentations during which responding was rewarded according to a VR 2 schedule. For the first 12 trials the ITI was 11 sec, for the second 12 trials it was 21 sec, and for the final 12 trials it was 41 sec. The next ten sessions each consisted of 12 trials; each trial was preceded by a 20-sec pre-trial period, and a variable-duration ITI of mean duration 80 sec (range: 50–110 sec). The trial, pre-trial period, and ITI remained at these durations for the rest of the experiment. During the first two of these sessions the reinforcement schedule was set at VR 2 and increased by one on each successive session to end
at VR 6. From this point, unless stated otherwise, the schedule was set at VR 6 during all trials on which response-contingent reinforcement was delivered.

**Discrimination Training.** The first two sessions in this stage were each composed of 12 Sd–f trials and 12 Sd–s trials, which were intermixed in a semi-random order. In the next session two new types of trial were introduced. Sd–f and Sd–s trials, during which response-contingent reinforcement was delivered as before, continued to occur; in addition, Sd–f was sometimes presented in compound with Lf, and Sd–s in compound with Ls. Lf and Ls were provided by the two visual stimuli, light and dark, which were counterbalanced across type of discriminative stimulus (clicker and noise) and type of reinforcer (food or sucrose). During these Sd/L compound trials no reinforcers were ever delivered. During each of these twelve 24-trial sessions there were nine Sd–f trials, nine Sd–s trials, three Sd–f/Lf and three Sd–s/Ls trials. The different types of trials were intermixed in a semi-random order.

**Test.** At this point the subjects were divided into two groups. In each of the next three sessions there were 12 presentations of Lf and 12 of Ls, intermixed in a semi-random order. All subjects received reward for responding during these trials, but the nature of the reward differed between the groups. Subjects in Group C were rewarded with food during presentations of Lf and with sucrose during presentations of Ls; animals in Group I received the opposite arrangement, being rewarded with food during Ls and with sucrose during Lf. The schedule during the first session was VR 3 and during the remaining sessions VR 6.

**Results**

One subject died from a respiratory infection during the course of the experiment; the group mean score was substituted for this animal’s data in all analyses.

**Discrimination Training.** The top panel of Table 2 shows the mean corrected response scores for the two groups for Sd alone and Sd/L compound trials during the last session of discrimination training. Scores are presented separately for food-rewarded and sucrose-rewarded responding. It may be seen that subjects responded substantially more during the Sd alone than during Sd/L trials. An analysis of variance with Group (C or I), Trial (Sd or Sd/L compound), and Reinforcer (food or sucrose) as factors revealed a significant main effect of Trial, $F(1, 14) = 169.4, p < 0.001$. No other effects or interactions were significant [largest $F(1, 14) = 2.66$]. The bottom panel of Table 2 shows the corresponding mean pre-trial response rates. An analysis
TABLE 2
Group Mean Response Rates for Sd and Sd/L Trials During
the Last Discrimination Training Session of Experiment 2

<table>
<thead>
<tr>
<th></th>
<th>Sd</th>
<th></th>
<th>Sd/L</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food</td>
<td>Sucrose</td>
<td>Food</td>
<td>Sucrose</td>
</tr>
<tr>
<td>During trial</td>
<td>52.38</td>
<td>53.86</td>
<td>2.29</td>
<td>9.71</td>
</tr>
<tr>
<td>Group C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group I</td>
<td>48.62</td>
<td>45.46</td>
<td>4.87</td>
<td>7.37</td>
</tr>
<tr>
<td>During pre-trial period</td>
<td>1.14</td>
<td>1.43</td>
<td>1.14</td>
<td>1.00</td>
</tr>
<tr>
<td>Group C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group I</td>
<td>0.25</td>
<td>0.08</td>
<td>0.25</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Response rates = responses per minute.

of variance performed on these data, again with Group (C or I), Trial (Sd or Sd/L) and Reinforcer (food or sucrose) as factors, revealed no significant effects or interactions [largest $F(1, 14) = 3.47$], except for a significant three-way interaction, $F(1, 14) = 7.78, p = 0.014$. However, it seems unlikely that this fluctuation in the pre-trial rates could have produced the significant effect of trial in the corrected scores as an artefact, as it was not mirrored in the corrected scores, where the three-way interaction was not significant ($F<1$).

Test. The test session data are shown in Figure 2. Following the procedure used in previous experiments (e.g. Bonardi, 1988b), the response rates were converted into elevation ratios. These were of form $a/(a+b)$, where $a$ is the total number of responses made during stimulus presentations and $b$ the total number of responses made during the pre-trial periods. The higher the ratio, the greater the ability of the stimulus to elicit responding. Ratios were calculated separately for each session and averaged over the three sessions. The ratio scores were substantially lower for Group C, for which the response contingencies in the test session directly contradicted those imposed during discrimination training, than for Group I, for which they did not.

An analysis of variance performed on the ratio scores with Group (C or I) as a factor revealed a significant main effect of Group, $F(1, 14) = 5.59, p = 0.033$. The rates of pre-trial responding did not appear to differ between
the groups; the mean rate of responding in the pre-trial periods was 6.48 rpm for subjects in Group C and 6.57 rpm for subjects in Group I. An analysis of variance performed on these scores with Group (C or I) as a factor showed that this difference was not significant ($F < 1$).

**Discussion**

In this experiment, animals were trained that during stimulus Lf responding would not be reinforced with food, and that during stimulus Ls responding would not be reinforced with sucrose. As a result of this training animals in Group C, required to learn to respond for food during Lf and for sucrose during Ls, showed a lower level of responding than animals in Group I, which had to learn the opposite discrimination and respond for sucrose during Lf and for food during Ls. This suggests that the ability of the S deltas, Lf and Ls, to suppress responding was specific to the reinforcer whose nonoccurrence they had signalled during training. It is also possible to construct an account of these results in terms of generalization decrement, as was the case in Experiment 1, but such an account is no more compelling than it was in that instance. In the present experiment one could argue that, for animals in Group I, a given S delta acquired its inhibitory properties while the animal was expecting the delivery of food, for example, whereas during the test the S delta would be experienced while the animal was learning to expect sucrose. If the nature of the expected reinforcer could alter the perception of the S delta, generalization decrement could result. It is not clear, however, how easily the perception of a stimulus could be altered in this way, and even if it could, it is still the case that at the end of training neither reinforcer can have been expected during either S delta. Thus the fact that during the test animals in Group I learned to expect sucrose during the S delta but Group C learned to expect food would not necessarily mean that Group I must be experiencing a greater change in conditions than Group C.
First, therefore, we may conclude that an S delta’s inhibitory properties appear to be reinforcer-specific as well as being response-specific. An instrumental adaptation of either Holland’s or Rescorla’s theory of negative occasion setting is therefore able to accommodate the functioning of these stimuli. Second, it is possible to argue that, if it is indeed justified to consider an S delta as a type of occasion setter, then this may also be viewed as a further demonstration that negative occasion setters are reinforcer-specific.

GENERAL DISCUSSION

The results of the second experiment suggest that the inhibition exerted by an S delta is reinforcer-specific, suggesting that the S delta satisfies the predictions made by instrumental versions of both Rescorla’s and Holland’s accounts of occasion setting. The results of the first experiment suggest that the effects of an S delta are also response-specific, which suggests that the S delta conforms to the predictions made by Holland’s theory of occasion setting but not to those made by Rescorla’s. Holland’s theory might thus provide an adequate explanation of inhibitory discriminative control.

At the start it was suggested that the traditional explanation of inhibitory discriminative control in terms of Pavlovian inhibitory conditioning had been challenged, and that a new theory was necessary. Although these experiments aimed to distinguish between various classes of such potential theories, they also constitute further grounds for rejecting the original Pavlovian account. A familiar characteristic of Pavlovian inhibitors is that they are not specific to the target CS with which they are established (Rescorla & Holland, 1977); the results of the first experiment are, therefore, not consistent with the proposition that the S deltas in this experiment were acting by virtue of Pavlovian inhibition. Moreover, although Pavlovian inhibitors are typically considered to be signals for the absence of a specific reinforcer, demonstrating that their action is specific to a particular reinforcer has proved extremely difficult, when one considers reinforcers in the same motivational class (Pearce, Montgomery & Dickinson, 1979; Nieto, 1984; but see Kruse, Overmier, Konz, & Rokke, 1983)—so much so that a major theory of inhibitory learning asserts that a Pavlovian inhibitor conveys no information at all about the sensory properties of the reinforcer whose omission it predicts (Dickinson & Dearing, 1979). The apparent ease with which reinforcer specificity was demonstrated in the second experiment thus leads one to suspect that Pavlovian inhibition was not involved. Thus, as well as creating difficulties for Pavlovian theories of discriminative control, these results also speak a fortiori against the formally identical account of negative occasion setting proposed by Rescorla.

The experiments reported here have been concerned with identifying those elements of the R–rf association upon which inhibitory discriminative stimuli
act. The results support the view that a discriminative stimulus functions in much the same way as Holland has supposed that an occasion setter does. It remains to specify what learning processes are involved in establishing a stimulus as an occasion setter (or as a discriminative stimulus). One possibility is that these mechanisms do not differ fundamentally from those underlying simple associative learning. Operationally, a positive occasion setter is present on the occasions when CS−US pairings occur, whereas a negative occasion setter is present on occasions when a CS+ is nonreinforced. It is possible to consider the central states engendered by a CS−US pairing or by CS+ nonreinforcement as being unitary events that can enter into associations just as can those produced by a CS or a US. Thus a positive occasion setter is correlated with one event, the CS−US pairing, and a negative occasion setter is correlated with another, CS+ nonreinforcement. It is then not necessary to depart from the principles of associative learning to explain the formation of occasion setters. Instead one could argue that a positive occasion setter becomes associated with the entire event of the CS−US pairing and that a negative occasion setter is similarly associated with the event of CS+ nonreinforcement.

This account, unlike Holland’s, makes some predictions about the conditions under which occasion setters may be formed—in particular these will be identical to those required for simple association formation. Take the case of a positive occasion setting procedure, where x is reinforced in the presence of A, A…x+, and nonreinforced when presented alone, x−. If occasion setting is the result of a simple association between the occasion setter and CS−US pairings, then pairing A with x+ should be sufficient for occasion setting to occur in this situation. Although it has often been assumed (e.g. Rescorla, 1985; 1988) that the x− trials are also necessary for A to become an occasion setter, there is in fact remarkably little data in the occasion-setting literature directly related to this issue (LoLordo & Ross, 1987).

REFERENCES


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