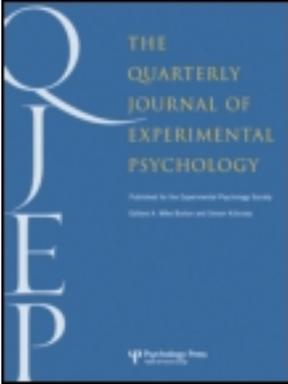


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### Associative explanations of discriminative inhibition effects

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## **Associative Explanations of Discriminative Inhibition Effects**

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In two experiments rats were trained to discriminate between trials signalled by a tone during which responding was reinforced, and trials signalled by the tone in compound with a light. During tone-light trials reinforcers were still delivered, but there was no contingency between responding and reinforcement. Subsequent transfer tests showed that the light had acquired the ability to suppress operant responding. Various explanations of this phenomenon are discussed. It is concluded that the data are inconsistent with traditional accounts of discriminative control.

A discriminative inhibitor may be defined as a stimulus that signals the absence of a response-reinforcer contingency. Such stimuli acquire the ability to suppress operant responding; the experiments reported here are concerned with the mechanism for this effect. Accounting for inhibition of responding poses a problem for most accounts of discriminative control. The S-R theories (e.g. Hull, 1952; Spence, 1956), upon which most of such accounts are based, generally appeal to competing responses to account for a reduction in the responding elicited by an established discriminative stimulus. A second mechanism for response inhibition may be derived from the so-called two-factor theories (e.g. Rescorla & Solomon, 1967; Trapold & Overmier, 1972). These are essentially S-R theories that, in addition, permit the value of the reinforcer to influence operant responding by means of a Pavlovian association between the discriminative stimulus and the reinforcer. A corollary of this idea is that a Pavlovian conditioned inhibitor, which by definition opposes the effects of Pavlovian excitation, might therefore suppress operant responding elicited by a discriminative stimulus. As discriminative inhibitors

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are typically established by being paired with nonreinforcement, this mechanism is easily invoked to explain almost all reported instances of the inhibitory properties of such stimuli (e.g. Brown & Jenkins, 1967; Cornell & Strub, 1965; Davis, 1971; Gutman, 1977; Gutman & Maier, 1978; Hearst & Peterson, 1973; Lyons, 1969; Yarczower, 1970; Yarczower & Curto, 1972). If this analysis is correct, a discriminative inhibitor suppresses operant responding either because it is a Pavlovian inhibitor or because it elicits some competing behaviour. This implies that no special properties accrue to a stimulus as a result of being paired with the absence of a contingency between responding and reinforcement. The experiments reported here attempt to test this idea.

### EXPERIMENT 1

In Experiment 1 subjects were rewarded for responding in the presence of a tone, but if the tone was presented in compound with a light, reinforcers were delivered at the same rate but independent of responding. The light is therefore a signal for the absence of a contingency between responding and reinforcement. However, most theories of classical conditioning predict that it should not acquire inhibitory strength, so that if the light suppresses operant responding, this cannot be because it is a Pavlovian inhibitor. On the other hand the light might acquire some excitatory strength and so elicit Pavlovian conditioned responses, which, S-R theory could argue, might compete with and so suppress instrumental behaviour. In order to investigate this possibility, before a summation test (in which the light's ability to suppress the responding elicited by a separately trained discriminative stimulus, a clicker, was assessed), half of the subjects (Group E) received a series of sessions in which the light was presented in extinction off the lever-pressing baseline, while the rest of the animals remained in the chambers but received no stimulus presentations. If this extinction stage can be shown to eliminate potential competing responses elicited by the light and yet has no effect on its ability to suppress operant responding, S-R theory cannot provide an explanation of these results.

The results of previous experiments (e.g. Gutman, 1977; Gutman & Maier, 1978) have shown that discrimination training of this type should indeed give the light the ability to suppress operant responding. However, these studies differed from the present experiments in two critical respects. First, they did not include an extinction stage, nor any other means of demonstrating that competing responses could not account for the suppression of responding produced by their target stimulus. Second, they used a different comparison in the summation test procedure. In order to show that the target stimulus produces suppression as a result of its learned properties (rather than by some nonassociative mechanism such as generalization

decrement or external inhibition) it is necessary to show that it is more effective than a control stimulus. In their summation test Gutman (1977) and Gutman and Maier (1978) used a control procedure in which the subjects received extensive exposure to a stimulus that was superimposed on the lever-pressing baseline without signalling any change in the reinforcement contingencies. Such a procedure would allow any potentially disruptive responses evoked by this stimulus to habituate, and the greater effectiveness shown by the trained target stimulus on the summation test might indicate only that the training given to this stimulus served to attenuate habituation (cf. Pfautz, Donegan & Wagner, 1978). Accordingly, the present experiment adopted the more conservative procedure of comparing the target stimulus against a quite novel control stimulus in the summation test.

Finally a Pavlovian savings test was conducted. This was firstly to establish that the light had indeed come to elicit Pavlovian conditioned responding as a result of discrimination training, and secondly to ensure that the extinction stage had succeeded in eliminating this responding in Group E. For both groups the light and the novel control stimulus were paired with food off the lever-pressing baseline. The speed of acquisition of conditioned responding to the light relative to that for the novel stimulus was taken as an index of the light's Pavlovian excitatory strength.

## Method

### *Subjects*

The subjects were 32 experimentally naive male hooded Lister rats with a mean free-feeding weight of 306 g (range: 280–350 g). Before the start of training they were gradually reduced to 80% of their free-feeding weights and were maintained at this level for the rest of the experiment by being fed a restricted amount of food at the end of each session.

### *Apparatus*

The apparatus consisted of four Campden Instruments lever-boxes, modified by the permanent removal of the right-hand of the two levers and 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 magazine covered by a Perspex flap door. A retractable rat lever was mounted to the left of the magazine opening; 45 mg mixed-composition food pellets could be delivered into the magazines of each chamber. Illumination was provided by a 2.8-W houselight wired in series with a 100- $\Omega$  resistor, mounted centrally in the rear wall. The houselight was on all the time the animals were in the chambers except during the visual light-off stimulus; another visual stimulus, light-on, was provided by turning on the strip light. Above the houselight

was a loudspeaker through which a 3000-Hz tone and a white noise pulsed at approximately 2Hz could be delivered from a Campden Instruments audio generator and a white noise generator. A third auditory stimulus, a clicker, was provided by operating a heavy-duty relay mounted near the front panel five times a second. All auditory stimuli were approximately 80 dB. Masking noise was provided by the operation of the ventilating fans. The apparatus was controlled by Acorn Atom microcomputers programmed in ONLIBASIC.

### *Procedure*

*Preliminary Training.* During the first, 30-min session the animals were magazine trained. The levers were removed from the chambers and food pellets were delivered at variable intervals with a mean of 60 sec. In the next session the levers were replaced and lever-pressing was consistently reinforced until each subject had earned a minimum of 75 pellets. During the third and fourth sessions subjects were pre-exposed to the stimuli. Lever-pressing was reinforced according to a variable interval (VI) 30-sec schedule, and subjects were exposed to 40-sec stimulus presentations without programmed consequence. During the first 45-min session the clicker and tone were each presented once, and the stimulus compounds clicker/light-on, tone/light-on, clicker/light-off, and tone/light-off were each presented twice. During the second 22-min session the light-on and light-off stimuli were each presented twice.

From this point all trials were discrete, signalled, and of 40-sec duration unless stated otherwise. All trials were separated by an intertrial interval (ITI) during which no reinforcers or stimuli were presented. Except in the initial sessions when the trials were longer than the ITI, each trial was always preceded by a pre-trial period of the same duration as the trial during which responses were recorded separately. In order to correct for individual differences in baseline responding, pre-trial response scores were subtracted from the scores recorded in the immediately following trial. Response rates to a given stimulus were calculated by pooling the "corrected" scores for all trials of that type in a session.

During the next five 20-trial sessions lever-pressing was reinforced according to a variable ratio (VR) schedule, during presentations of the clicker in the first four sessions and during equal numbers of presentations of the clicker and the tone in the fifth. The value of the VR schedule was increased in steps of two or four from VR 4 to VR 16. The length of the ITI was initially 21 sec, increased in later sessions to 41 sec. For the remainder of the experiment the value of the VR schedule was maintained at VR 16, with the following additional constraints. First, if a subject made 48 consecutive unrewarded responses, the next response earned a pellet. Second, no more

than six pellets could be earned in any trial. Finally, VR trials were programmed in 1-sec intervals in order to accommodate the yoking procedure described below. If a reward was delivered, then for the rest of that interval responses were not recorded and hence no more reinforcers could be earned. Unless stated otherwise, for the remainder of the experiment the ITI was of variable duration with a mean of 80 sec (range: 50–110 sec). The next three sessions consisted of 16 VR trials, eight signalled by the clicker and eight by the tone. These different types of trial were intermixed in a semi-random order.

*Discrimination Training.* There were 28 sessions of discrimination training, each consisting of 24 trials. During 16 of these trials responding was rewarded according to the VR 16 schedule described above; 8 of these trials were signalled by the clicker and 8 by the tone. The other 8 trials were signalled by the tone in compound with one of the visual stimuli. For half of the animals this was the light-on, and for half it was the light-off stimulus; for ease of reference both will be referred to as tone-light trials. During these variable time (VT) tone-light trials, reinforcers were delivered according to a yoking procedure, which ensured that the number and temporal distribution of reinforcers delivered on any one (VT) trial was identical to that earned by the same subject during a preceding tone trial. A VT trial could not occur more than five trials after the VR trial to which it was yoked. The different types of trial were intermixed in a semi-random order. All but two of the 28 sessions were of this format; Sessions 21 and 22 differed in that they consisted only of 12 tone trials and 12 tone-light trials.

At the end of discrimination training subjects not reaching a performance criterion were discarded. A ratio was computed for each session by dividing the corrected score for tone-light trials by that for tone trials. If either of these corrected scores was negative, the raw trial scores were used. The lower the ratio, the less the responding during VT trials relative to VR trials and hence the better the discrimination. All subjects for whom this ratio had not been equal to or less than 75% on at least one of the last five discrimination sessions were discarded, leaving 22 rats to complete the experiment.

*Pavlovian Extinction Stage.* The animals were then divided into two groups of 11. The levers were removed from the chambers, and during four sessions subjects from Group E received 24 presentations of the visual stimulus used in discrimination training. Subjects in Group N spent the same amount of time in the chambers but received no stimulus presentations. No reinforcers were delivered during these sessions. The number of magazine entries made during trial and pre-trial periods was recorded by means of a microswitch fastened to the back of the magazine flap.

*Operant Summation Test.* The levers were returned to the chambers and

subjects were given a single session of the operant summation test. There were 24 trials: 8 presentations of the clicker alone, 8 of the clicker in compound with the visual stimulus used in discrimination training, and 8 of the clicker in compound with the other, novel visual stimulus. Half of each of these types of trial were paired with a VT 12-sec schedule of response-independent reinforcement, with the additional constraint that at least one reinforcer would be delivered per trial. During the remainder of the trials no reinforcers were delivered. The six different types of trial were presented in a semi-random order.

*Pavlovian Savings Test.* The levers were again removed from the chambers, and subjects were given eight sessions of a Pavlovian savings test. Each session consisted of 24 trials, during which the visual stimulus used in discrimination training and the novel visual stimulus were each presented 12 times in a double alternation sequence. At the offset of each stimulus presentation, a single food pellet was delivered. For the first three of these sessions, the trials were of 40-sec duration; for the remaining sessions, the trial and pre-trial period duration were reduced to 20 sec and the ITI increased to a mean of 100 sec (range 70–130 sec), so that the total (mean intertrial interval + trial duration) was the same as in previous stages of the experiment. The number of magazine entries made during trial and pre-trial periods was recorded.

## Results

In all analyses reported below, a significance level of  $p < 0.05$  was adopted. Lever-pressing scores were examined using analysis of variance. Significant effects and interactions in preplanned comparisons were examined with  $F$  or  $t$  tests. Magazine-entry scores showed considerable nonhomogeneity of variance and were subject to nonparametric analysis; preplanned comparisons were made using one-tailed tests; otherwise two-tailed tests were used.

*Discrimination Training.* Response rates in the presence of the various stimuli on the last day of discrimination training for subjects meeting the performance criterion are presented in Table 1. These data, based on corrected (i.e. trial–pre-trial) scores converted into responses per minute (rpm), are presented separately for Groups E and N. Subjects showed a clear discrimination, responding at a higher rate on VR than on VT trials. Statistical analyses confirmed this description.

A three-way analysis of variance with Group (E or N), Type of Trial (clicker, tone, or tone–light) and type of Visual Stimulus (light-on or light-off) as factors was performed on these data. There was a significant main effect of Trial Type,  $F(2, 36) = 33.03$ , and a significant interaction between

TABLE 1  
Corrected Group Mean Response Rates\* in  
Clicker, Tone, and Tone-Light Trials during  
the Last Discrimination Training Session of  
Experiment 1

	<i>Clicker</i>	<i>Tone</i>	<i>Tone-Light</i>
Group E	75.85	75.94	26.81
Group N	70.69	72.37	23.06

\* Responses per minute.

Trial Type and Type of Visual Stimulus,  $F(2, 36) = 3.71$ . No other effects or interactions were significant ( $F_s < 1$ ). A planned comparison confirmed that responding was significantly lower during tone-light trials than during tone trials,  $t(36) = 7.11$ . Better discrimination was shown by subjects trained with the light-on stimulus than by those trained with the light-off stimulus. The mean response rates for tone and tone-light trials were 76.12 and 10.31 rpm for subjects trained with the light-on, and 71.81 and 42.56 rpm for those trained with the light-off. The mean pre-trial response rates were 9.11, 9.64, and 9.21 rpm for clicker, tone, and tone-light trials, respectively. A three-way analysis of variance with Group (E or N), Type of Visual Stimulus (light-on or light-off), and Type of Trial (clicker, tone, or tone-light) as factors revealed no significant effects or interactions [largest  $F(2, 36) = 1.14$ ]. Hence the reported differences in the corrected trial response rates cannot be attributed to differences in pre-trial responding.

*Pavlovian Extinction Stage.* Corrected scores were derived from the number of magazine entries made by subjects in Group E during presentations of the visual stimulus, subtracting prestimulus entries as described above. The mean score per session was 14.25 entries averaged over the first two sessions, and 0.25 averaged over the last two sessions. These scores differed significantly, Wilcoxon  $T(11) = 0$  (one-tailed), suggesting that magazine behaviour had declined as a result of the extinction procedure. Pre-trial response rates of magazine entry also declined. The mean pre-trial score per session was 25.1 entries averaged over the first two sessions, and 17.25 averaged over the last two sessions. These scores also differed significantly, Wilcoxon  $T(9) = 1$ .

*Operant Summation Tests.* Performance in the operant summation test was analysed using suppression ratios of the form  $a/(a + b)$ , where  $a$  is the total number of responses made during trials signalled by the clicker in compound with a visual stimulus and  $b$  the number made during trials signalled by the clicker alone. A ratio of less than 0.5 means that the visual

stimulus suppressed responding elicited by the clicker. Separate ratios were calculated for test trials with each reinforcement schedule and averaged to produce for each subject one value for suppression produced by the visual stimulus used in training, and one for the suppression produced by the novel visual stimulus. The resulting data are presented in Figure 1. They show that greater suppression of responding was produced by the visual stimulus used in discrimination training than by the novel visual stimulus. There was no indication that this effect had been diminished by the extinction treatment given to Group E. On the contrary, the difference between trained and novel visual stimuli was slightly larger in Group E than in Group N.

Mean response rates during clicker trials were 80.77 rpm for Group E and 89.85 rpm for Group N. A one-way analysis of variance showed that these scores did not differ ( $F < 1$ ). Mean pre-trial response rates for clicker trials were 13.35 rpm for Group E and 9.41 rpm for Group N. A one-way variance showed that these scores did not differ ( $F < 1$ ).

A two-way analysis of variance with Group (E or N) and Training history of visual stimulus (trained or novel) as factors was performed on the ratio scores. A covariate was included to correct for individual differences in the unconditioned effects of the two visual stimuli. This was the averaged corrected score from visual stimulus presentations during the pre-exposure session preceding discrimination training. There was a significant main effect of the Training history of the visual stimulus,  $F(1, 19) = 13.87$ , which did

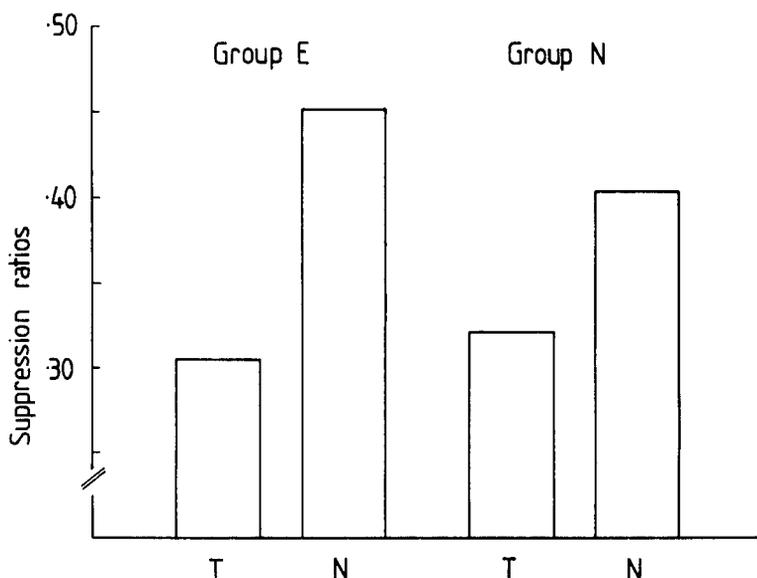


FIG. 1. Group mean suppression ratios for trained (T) and novel (N) visual stimuli, adjusted for the covariate, from the operant summation test of Experiment 1.

not interact with Group [ $F(1, 19) = 1.08$ ]. There was no main effect of Group ( $F < 1$ ). This pattern of results confirmed that discrimination training gave the visual stimulus the ability to suppress operant responding more than a novel control stimulus, and that this pattern of response suppression was unaffected by the extinction procedure. Mean pre-trial response rates were 11.17 rpm for trials signalled by the clicker in compound with the visual stimulus used in training and 10.01 rpm for those signalled by the clicker in compound with the novel visual stimulus. A two-way analysis of variance with Group (E or N) and Training History of Visual Stimulus (trained or novel) as factors was performed on these scores and revealed no significant effects or interactions [largest  $F(1, 20) = 1.41$ ]. One may therefore conclude that the results of the ratio score analysis cannot be attributed to differences in pre-trial responding.

*Pavlovian Savings Test.* Data are presented for the sessions in which the trial duration was 20 sec. Figure 2 shows the group mean corrected scores for magazine entries made over the final five sessions during presentations of the trained and novel visual stimuli. The trained visual stimulus elicited more magazine behaviour than the novel visual stimulus in both groups, but this difference was slightly smaller in Group E than in Group N.

Interpretation of these differences is complicated by differences between the groups in pre-trial responding. The total number of pre-trial responses in Group E was 113.4 for trials signalled by the trained visual stimulus and

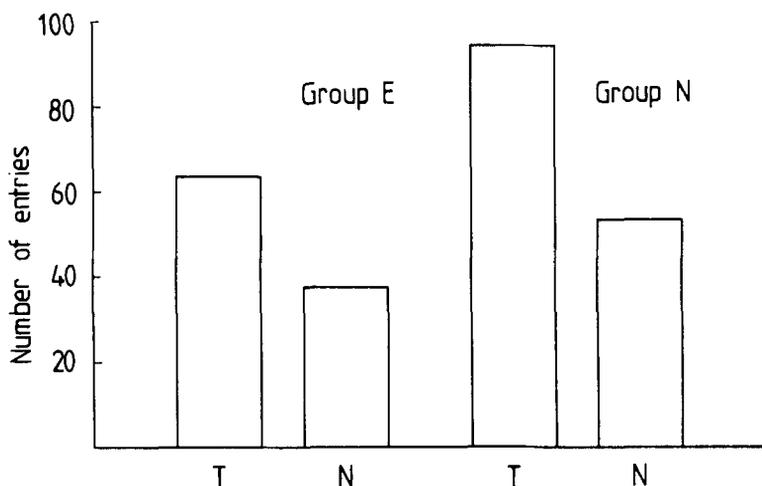


FIG. 2. Group means of the number of magazine entries made during trained (T) and novel (N) visual stimulus presentations, pooled over the Pavlovian savings test sessions of Experiment 1. Scores are corrected for pre-trial responding.

104.1 for those signalled by the novel visual stimulus. The equivalent scores for Group N were 52.9 and 55.4, respectively. Comparing the scores for the two groups pooled over both trial types showed there to be a significant difference between them, Mann-Whitney  $U(11, 11) = 26.5$ . This difference perhaps reflects the fact that the presence of the food-associated light during the extinction phase for Group E protected from extinction any response-eliciting properties the context itself might have possessed. Whatever its source, this difference in pre-trial responding makes direct comparisons between the groups illegitimate. We may, however, make within-group comparisons of the scores for the two stimuli. These revealed a significant difference in Group N, Wilcoxon  $T(11) = 10$  (one-tailed), but not in Group E [ $T(11) = 16$ ], suggesting that Pavlovian excitatory properties had been acquired by the light as a result of discrimination training and that these had been somewhat reduced by the extinction phase in Group E.

## Discussion

The results of this experiment suggest that a stimulus paired with response-independent reinforcement may suppress the responding otherwise elicited by a separately trained discriminative stimulus. This is consistent with the findings of Gutman and Maier (1978), despite the use of a summation test considerably more conservative than the one that they employed. As presenting the light along with response-independent reinforcement endowed it with Pavlovian excitatory strength, this suppression of responding cannot be attributed to Pavlovian inhibition. Moreover, it is not clear that competing responses can be held responsible either. An extinction treatment that significantly reduced the level of classically conditioned responding to the light—and hence, it might be reasonable to suppose, also reduced the level of any other competing behaviours it elicited—had no effect on its ability to suppress operant responding. This suggests that discrimination training endowed the light with some property lying outside the scope of S-R theory that allowed it to suppress operant responding.

It may, nevertheless, be possible to supply an account of these results in terms of classical conditioning if it is allowed that the excitatory properties of the light, apparently lost by the end of the extinction phase in Group E, were subject to spontaneous recovery and therefore capable of exerting an influence in the operant summation test. Certainly the results of the final Pavlovian savings test suggest that the extinguished light (in Group E) had retained some excitatory strength, as acquisition occurred to this stimulus more readily (although not significantly so) than to a novel control stimulus. Two other aspects of the data speak against this interpretation, however. First, there was no sign of spontaneous recovery in the extinction phase in Group E. On the final two sessions of extinction the light evoked virtually no

magazine responses. Second, no matter how substantial the recovery in Group E, the conditioned responding evoked by the light in this group would still be less than that evoked by the non-extinguished light in Group N. There was, however, no reliable difference between the two groups in the operant summation test; if anything, the light was a more effective inhibitor in Group E than in Group N.

## EXPERIMENT 2

A major concern up to this point has been to challenge S-R theory by showing that the light does not suppress operant responding by interfering with the Pavlovian association between the discriminative stimulus and the reinforcer. It remains possible, however, that instead it suppresses responding by interfering with the S-R association itself. In general, two-factor theories assume that S-R associations are strengthened by contiguity between response and reinforcer, and some versions explicitly predict (e.g. Hull, 1952) that a stimulus may acquire the ability to suppress operant responding by being paired with a reduction in the frequency of response-reinforcer pairings. If this is the case, both the results of Experiment 1 and the data reported by Gutman (1977) and Gutman and Maier (1978) could be explained. Experiment 2 attempted to test this hypothesis. The procedure was virtually identical to that of Experiment 1, with some critical alterations. As in Experiment 1, subjects received tone trials during which there was a contingency between responding and reinforcement and tone-light trials during which this contingency was absent. In contrast to Experiment 1, the probability of a response being reinforced was the same during the tone whether or not the light was present. The response-reinforcer contingency was removed during tone-light trials by delivering extra reinforcers, so that the probability of reinforcement in any second was the same, whether or not a response had occurred. Although the light signalled the absence of the response-reinforcer contingency, it did not signal a reduction in the frequency of response-reinforcer pairings. The additional response inhibition mechanism postulated by S-R theory cannot therefore account for the light suppressing operant responding in this instance.

In a further modification of the procedure of Experiment 1, an attempt was made to improve the reliability of the final savings test as a measure of any residual excitatory strength possessed by the light. First, all subjects were left in the context for one session immediately before the savings test without any stimulus presentations or reinforcer deliveries. This measure was intended to minimize any differences between the groups in context excitation that might have arisen in the course of the extinction procedure. The second modification related to the measure of Pavlovian conditioning used. If Pavlovian conditioned responding to the light competes with operant

responding, it is because the animal is engaged in magazine behaviour in time during which it could be lever-pressing. It is therefore reasonable to suppose that the time spent in the magazine during the light is a more direct measure of the degree to which the light can prevent operant responding than the number of magazine entries. It is also reasonable to argue that it is a better measure of Pavlovian conditioning per se. In the limit one could imagine that an animal might make a single magazine entry for the entire duration of the stimulus presentation, and yet one would not want to argue that this animal had not formed a strong Pavlovian association between that stimulus and food. Hence the amount of time subjects spent with the magazine flap open rather than the number of magazine entries was recorded in this experiment.

## Method

### *Subjects and Apparatus*

The subjects were 24 experimentally naive male hooded Lister rats with a mean free-feeding weight of 273.7 g (range: 255–290 g). They were housed in groups of four and maintained at 85% of their free-feeding weight by being given an hour's access to food at the end of each day's sessions. The same apparatus was used as in Experiment 1.

### *Procedure*

*Preliminary Training.* This was identical to that described for Experiment 1, except that all initial pre-exposure trials occurred in a single 60-min session, and presentations of the tone in compound with the novel visual stimulus were omitted. The schedule according to which responding was reinforced during VR trials was identical to that used in Experiment 1, except for the fact that only the first response made in any 1-sec unit had the opportunity of being reinforced. (In Experiment 1 the only responses made during a VR trial that did not have the opportunity of being reinforced were those made in a particular 1-sec unit after a response in that unit had already been reinforced.) This change was introduced to allow programming of free reinforcers during tone–light trials. There were 12 sessions, each consisting of 16 trials, during which responding was reinforced according to this modified VR schedule. The first 7 sessions consisted solely of clicker trials, the next 2 of equal numbers of clicker and tone trials, the next 2 of only tone trials and the final one of equal numbers of clicker and tone trials. The ITI was increased from 21 to 41 to 60 sec, before being fixed at a variable duration of mean 80 sec. The probability of food given a response in each 1-sec interval during VR trials was decreased in steps from 0.33 to 0.0625, at which value it remained for the rest of the experiment. In all other respects this stage was identical to the corresponding stage of Experiment 1.

*Discrimination Training.* There were 28 sessions in this stage, each consisting of 18 trials. In contrast to Experiment 1, trials with the clicker did not occur in every session. The first session and every third session thereafter consisted of 6 presentations each of the tone, clicker, and tone–light compound, while the remaining sessions consisted of 9 presentations each of the tone and the tone–light compound. The response–reinforcer contingency described above was in operation during every trial. In addition, during tone–light trials extra reinforcers were delivered; if no response had been made during any 1-sec unit, a reward was delivered with probability 0.0625. In all other respects, discrimination training was the same as in Experiment 1.

After discrimination training, the performance criterion used in Experiment 1 was applied to identify subjects showing poor discrimination, leaving 19 animals to complete the experiment.

*Extinction Stage.* At this point the subjects were divided into two groups. Group E ( $n=9$ ) received nine extinction sessions each consisting of 18 presentations of the visual stimulus that had been used in training. Group N ( $n=10$ ) was left in the chambers for the same amount of time. The time spent in the magazine during trial and pre-trial periods was recorded. Other aspects of this stage were identical to the corresponding stage in Experiment 1.

*Operant Summation Test.* Both groups then received six sessions of an operant summation test, exactly as in Experiment 1, except that the number of trials per session was reduced to 18 and the VT schedule used was VT 20-sec. It was hoped that these changes might result in less acquisition of Pavlovian excitatory strength by the trained and novel visual stimuli during the test, and that perhaps this might make differences in the subsequent Pavlovian savings test easier to detect.

*Pavlovian Savings Test.* At this point the levers were removed from the chambers and all subjects were given a preliminary 40-min session during which no stimulus presentations or rewards were delivered. In each of the subsequent 16 Pavlovian savings test sessions all subjects received 8 presentations each of the trained and novel visual stimuli. All stimulus presentations and pre-trial periods were of 20-sec duration. The time spent in the magazine during trial and pre-trial periods was measured. In all other respects this test was identical to that of Experiment 1.

## Results

*Discrimination Training.* Response rates in the presence of the various stimuli on the last day of discrimination training for subjects meeting the

performance criterion are shown in Table 2. These data, based on corrected (i.e. trial-pre-trial) scores converted into rpm, are presented separately for Groups E and N. Once more subjects showed a clear discrimination, responding at a higher rate on VR trials than on VT trials. Statistical analysis confirmed this description. A three-way analysis of variance with Group (E or N), Type of visual stimulus (light-on or light-off), and Trial type (clicker, tone, or tone-light) as factors was performed on these data. There was a significant main effect of trial type,  $F(2, 30) = 7.91$ , but no other effects or interactions were significant ( $F_s < 1$ ). A planned comparison showed that there was significantly less responding during tone-light trials than during tone trials,  $t(30) = 3.40$ . The mean pre-trial response rates during this session were 8.42 rpm for clicker trials, 4.17 rpm for tone trials, and 6.37 rpm for tone-light trials; thus, responding was slightly lower before tone trials than before tone-light trials, an effect that would tend to obscure discrimination performance. A three-way analysis of variance with Group (E or N), Type of visual stimulus (light-on or light-off), and Trial type (clicker, tone, or tone-light) as factors was performed on the pre-trial scores for the last session. This revealed a significant main effect of Trial type,  $F(2, 30) = 8.92$ . No other effects or interactions were significant [largest  $F(1, 15) = 1.89$ ].

During those sessions that were composed solely of tone and tone-light trials, the mean number of reinforcers per trial was 0.98 for VR trials and 2.44 for VT trials. A three-way analysis of variance with Group (E or N), Type of visual stimulus (light-on or light-off), and Trial type (tone or tone-light) as factors showed that there was a significant main effect of Trial type,  $F(1, 15) = 191.13$ . There were no other significant effects or interactions ( $F_s < 1$ ). Thus the visual stimulus signalled an increase in the rate of food delivery during this stage, and the groups did not differ in this respect.

*Pavlovian Extinction Stage.* Corrected scores were derived from the time spent in the magazine during presentations of the visual stimulus by subjects in Group E. The mean score per session was 18.41 sec averaged over the first four sessions and 5.57 sec averaged over the last four sessions. These scores differed significantly, Wilcoxon  $T(9) = 7$  (one-tailed), suggesting that maga-

TABLE 2  
Corrected Group Mean Response Rates\* in  
Clicker, Tone, and Tone-Light Trials during  
the Last Discrimination Training Session of  
Experiment 2

	<i>Clicker</i>	<i>Tone</i>	<i>Tone-Light</i>
Group E	36.15	32.65	21.00
Group N	38.72	41.17	23.42

\* Responses per minute.

zine behaviour decreased as a result of the extinction procedure. Pre-trial scores increased slightly over the course of extinction. The mean pre-trial score per session was 22.57 sec averaged over the first four sessions and 30.71 sec averaged over the last four sessions. A Wilcoxon T-test showed that this increase was not significant [ $T(9) = 13$ ].

*Operant Summation Test.* Data from the operant summation test were converted into suppression ratios, exactly as in Experiment 1. Six operant summation test sessions were given. Group mean suppression ratios for the trained and for the novel visual stimulus were calculated separately for the first and second block of three sessions. The resulting data are shown in Figure 3. In accordance with the results of Experiment 1, they show that responding during the clicker was suppressed more by the visual stimulus used in training than by the novel visual stimulus. This pattern showed some change over sessions; in the first block the trained stimulus was more suppressive in Group N than in Group E, whereas in the second block it was, in contrast, more suppressive in Group E than in Group N.

The mean response rate during clicker pre-trial periods was 5.91 rpm for Group E and 5.87 rpm for Group N. Responding decreased over the course of testing; the mean response rate was 7.98 rpm for the first block of sessions and 3.80 rpm for the second. A two-way analysis of variance with Group (E or N) and Block (first or second three-session block) as factors revealed a

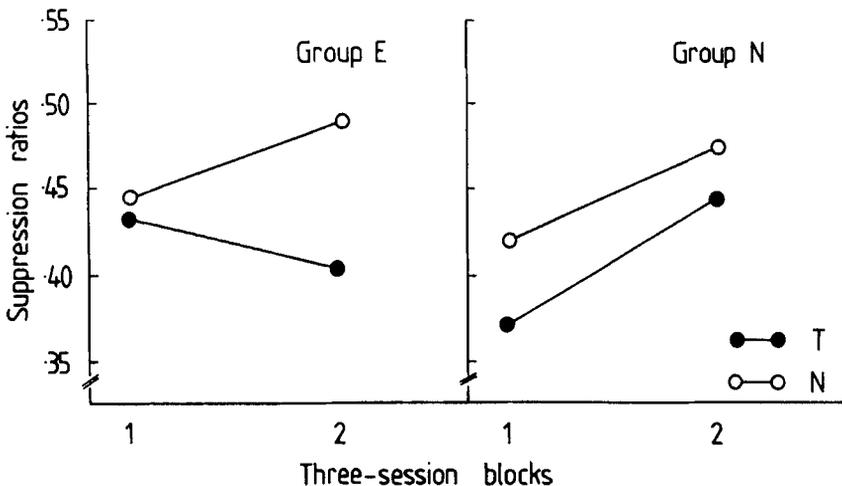


FIG. 3. Group mean suppression ratios for trained (T) and novel (N) visual stimuli, adjusted for the covariate, from the operant summation test of Experiment 2, as a function of three-session blocks.

significant main effect of Block,  $F(1, 15) = 25.68$ , but no other significant effects or interactions ( $F < 1$ ). The mean response rate during clicker trials was 26.4 rpm for Group E and 29.4 rpm for Group N. Responding decreased over the course of testing; the mean response rate was 33.2 rpm for the first block of sessions and 22.8 rpm for the second. A two-way analysis of variance with Group (E or N) and Block (first or second three-session block) as factors revealed a significant main effect of Block,  $F(1, 17) = 40.83$ , but no other significant effects or interactions [largest  $F(1, 17) = 1.09$ ].

A three-way analysis of variance with Group (E or N), Training history of visual stimulus (trained or novel), and Block (first or second three-session block) as factors, and which included the covariate described for Experiment 1, was performed on the ratio scores. There was a significant main effect of the Training history of the visual stimulus,  $F(1, 16) = 6.14$ , which did not interact with group ( $F < 1$ ). This suggested that the visual stimulus used in discrimination training suppressed responding more than its novel counterpart, and that the size of this effect did not differ between the groups. There was a main effect of block,  $F(1, 17) = 5.70$ , and a significant three-way interaction,  $F(1, 17) = 5.41$ . This seemed to reflect the fact that in the first block the trained visual stimulus was more suppressive in Group N than in Group E—a pattern of results consistent with the idea that the extinction treatment reduced its suppressive properties—but that in the second block this pattern was reversed, implying precisely the opposite. On balance, therefore, it is not clear that these results could be explained by the extinction treatment reducing the suppressive properties of the trained visual stimulus in Group E. No other effects or interactions were significant [largest  $F(1, 17) = 3.00$ ].

The mean pre-trial response rate for trials signalled by the clicker in compound with the trained visual stimulus was 6.92 rpm, and 6.92 rpm for those trials on which the clicker was compounded with the novel visual stimulus. Rates decreased over the course of testing; the mean rate was 8.34 rpm for the first block and 5.50 rpm for the second. A three-way analysis of variance with Group (E or N), Training history of visual stimulus (trained or novel), and Block (first or second three-session block) was performed on these data. This revealed a main effect of Block,  $F(1, 17) = 10.05$ , but no other effects or interactions were significant [largest  $F(1, 17) = 1.10$ ]. One may therefore conclude that the results of the ratio score analysis cannot be attributed to the pattern of pre-trial responding.

*Pavlovian Saving Test.* Corrected scores for trained and novel visual stimulus presentations were averaged over the 16 sessions to produce two scores for each animal. The resulting group mean scores are presented in Figure 4. They suggest that the trained visual stimulus elicited more

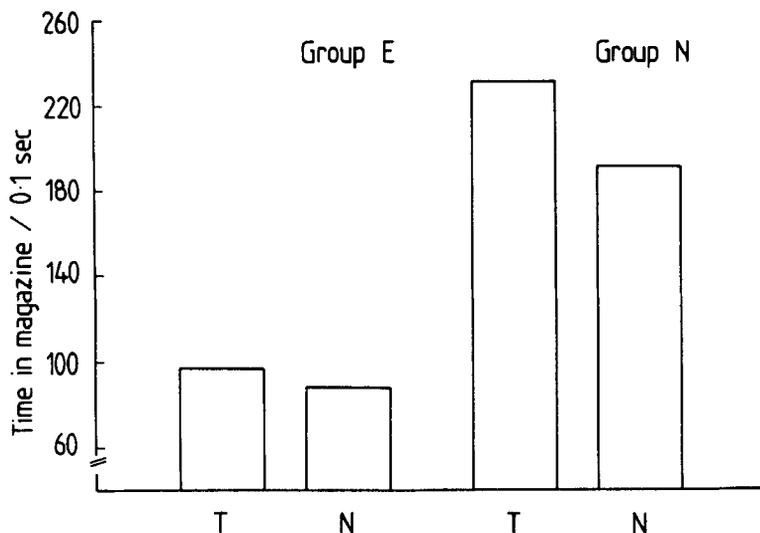


FIG. 4. Group means of the time spent in the magazine during trained (T) and novel (N) visual stimulus presentations, averaged over the Pavlovian savings test sessions of Experiment 2. Scores are corrected for pre-trial responding.

magazine activity than the novel stimulus in both groups, but that once more this difference was somewhat greater in Group N.

Mean pre-trial scores for trained and novel visual stimulus presentations, also averaged over all sessions, were 6.93 and 6.62 sec for Group E and 9.95 and 9.62 sec for Group N. In neither group did the pre-trial scores for the two types of trial differ significantly [Group N, Wilcoxon  $T(10)=20$ ; Group E  $T(9)=19$ ]. This suggests that in neither group can differences between the corrected scores for the two stimuli be attributed to the pattern of pre-trial responding. Nor did the groups differ from each other. A Mann-Whitney  $U$  test comparing the pre-trial scores of the two groups averaged over both types of trial revealed no significant difference between them [ $U(10, 9)=32$ ]. This suggests that the context extinction session succeeded in eliminating the differences in context excitation between the two groups that had been observed in Experiment 1.

There was no difference between the groups in their corrected scores for novel visual stimulus presentations [ $U(10, 9)=32$ ], or in their level of pre-trials responding for these trials [ $U(10, 9)=32$ ]. Hence, in order to minimize the effects of individual variations in response levels, the difference between the corrected scores for trained and novel visual stimulus presentations was compared in the two groups. A Mann-Whitney  $U$  test found that these difference scores indeed differed,  $U(10, 9)=22$  (one-tailed), and Wilcoxon  $T$  tests showed that there was significantly more magazine responding during

the trained visual stimulus than during the novel visual stimulus in Group N,  $T(10) = 10$  (one-tailed), but not in Group E,  $T(9) = 19$ . The results of this experiment therefore suggest that the extinction stage had been effective in reducing the Pavlovian excitatory properties of the trained visual stimulus in Group E.

## Discussion

The results of this experiment replicate those of Experiment 1 in finding that a stimulus that signalled the absence of a contingency between responding and reinforcement was found to suppress instrumental behaviour. As in Experiment 1, this stimulus possessed Pavlovian excitatory strength, so that its inhibitory effect could not be attributed to Pavlovian inhibitory conditioning, whereas an extinction treatment that significantly reduced its ability to elicit classically conditioned responses, and presumably also any other potential competing responses, had no effect on its ability to suppress operant responding. In addition, these results demonstrated that the stimulus acquired this property despite the fact that it signalled no reduction in the frequency of response-reinforcer pairings. It seems that S-R theory cannot provide an explanation for these data.

In this experiment the target stimulus acquired Pavlovian excitatory strength as a result of discrimination training, and this was significantly reduced during the extinction treatment given to Group E. Moreover, the savings test provided no indication that this Pavlovian excitatory strength showed spontaneous recovery. This result has implications for the results of Experiment 1, where the savings test results raised the possibility that recovery of the Pavlovian excitatory strength of the light might have occurred in Group E. In this study an attempt was made to improve the sensitivity of the savings test. The fact that the improved test provided no evidence of recovery supports the assertion that the reduction in magazine responding observed in Experiment 1 over the course of extinction was an accurate indication of the light's Pavlovian excitatory strength during the operant summation test. If this is the case, then the suppression of operant responding in that experiment too cannot be attributed to competition from classically conditioned responses.

## GENERAL DISCUSSION

In summary, these experiments demonstrate that a stimulus that signals the absence of a contingency between responding and reinforcement suppresses operant responding in a manner that cannot be accounted for by S-R theories of discriminative control. These results are consistent with those of Bonardi (submitted), who reported that a stimulus that signalled the absence of a response-reinforcer contingency by being paired with nonrein-

forcement showed no evidence of being a Pavlovian inhibitor and yet suppressed operant responding, whereas a stimulus that was a Pavlovian inhibitor had no effect on instrumental performance. They are also consistent with a growing body of evidence suggesting that associations between single events, such as the conditioned stimulus and the reinforcer in simple Pavlovian conditioning, may be inadequate as explanations of some learning phenomena. For example, discriminative stimuli appear to exert their control over operant responding independent of any Pavlovian association with the reinforcer (Holman & Mackintosh, 1981). Experiments on occasion setting in classical conditioning points to the same conclusion. Operationally, occasion setters are directly analogous to discriminative stimuli; just as discriminative stimuli and inhibitors signal the presence or absence of a contingency between responding and reinforcement, so positive and negative occasion setters signal the presence or absence of a contingency between another stimulus and reinforcement. There is good evidence that the properties of occasion setters cannot be explained in terms of Pavlovian conditioning (e.g. Holland, 1984; Ross, 1983; Ross & LoLordo, 1986).

It seems that some new theory is needed—one that is, for example, capable of accommodating the fact that it is sufficient for a stimulus to signal the absence of a response–reinforcer contingency for it to suppress operant responding. Mackintosh's (1983) suggestion is that we should accept that subjects are capable of accurately representing the contingencies that they experience. Moreover, it may not be necessary to assume that this cannot be an associative explanation. Just as a Pavlovian conditioned stimulus acquires its properties because it is associated with the reinforcer, so a discriminative stimulus might have its properties not because it is associated with a reinforcer (or the response) but because it is associated with a representation of the relationship between these two events. Likewise, just as Pavlovian inhibitors have been described operationally as signals for the omission of the reinforcer, so a discriminative inhibitor may be described as a signal for the absence of a response–reinforcer contingency. The analogy suggests that the same associative learning mechanism could in principle be responsible for both types of learning; the difference is the substitution of the response–reinforcer contingency for the reinforcer. In the long run it may be more parsimonious to accommodate such apparently nonassociative phenomena by expanding the scope of existing associative theory in this way.

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