# Analysis of Potentiation and Overshadowing Effects in the Instrumental Performance of Pigeons

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In each of two experiments, pigeons were trained on a multiple VI (variable interval) schedule with a 3-s delay of reinforcement. Different components were associated with different key colors. Experiment 1 (stage 2) confirmed a previous finding that the response rate is higher in a component having a signal (illumination of the houselight) filling the delay interval than in a component lacking the signal. This potentiation effect was replaced by an overshadowing effect (i.e., the rate was low in the signaled component) when in stage 1 of Experiment 1 the birds received concurrent experience of a component containing houselight presentations not correlated with reinforcement. In Experiment 2 it was found that this overshadowing effect was abolished when the signal used was the presentation of a pattern on the response key rather than illumination of the houselight. These results are interpreted in terms of an interaction between the rate-enhancing properties of the signal (perhaps a consequence of its conditioned reinforcing power) and the tendency of the signal in some conditions to evoke behavior that competes with the response being recorded. © 1992 Academic Press, Inc.

Schachtman, Reed, and Hall (1987) investigated, in pigeons responding for food delivered on a variable interval (VI) schedule, the effects of presenting a signal during a delay between the reinforced response and the presentation of the reinforcer. The effect on response rate was found to depend on the duration of the delay. With a nominal delay of 0.5 s (since the birds often continued to respond during the interval, the length of the delay actually experienced was somewhat less), the presence of the signal resulted in a lowered response rate, an effect referred to as over-

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shadowing (see also Hall, 1982; Hall, Channell, & Schachtman, 1987). When, however, a nominal delay of 3 s was used, the effect of the signal was to maintain responding at a level higher than that supported by the equivalent unsignaled condition (see also Richards, 1981; Williams & Heyneman, 1982). This effect was referred to as potentiation.

Schachtman et al. (1987) attempted to interpret their results in terms of the explanations that have been offered for overshadowing and potentiation in classical conditioning. Most current theories of classical conditioning have followed Rescorla and Wagner (1972) in incorporating a mechanism whereby an event that reliably predicts reinforcement will gain associative strength at the expense of a less reliable predictor. Schachtman et al. (1987) suggested that the signal that fills a 0.5-s delay between response and reinforcer, being a reliable predictor, should become associated with food and by doing so might restrict the growth of a response–reinforcer association on which the rate of responding has been assumed to depend. At the longer response–reinforcer interval, however, the direct association between response and reinforcer will be likely to form only with difficulty and any tendency of the signal to overshadow such a weak association will be of little significance. In order to explain why the rate of response should actually be enhanced when a signal fills the 3-s delay, some new factor must be considered and Schachtman et al. turned to theories of potentiation developed for the effect seen in other training situations. Two such theories can be readily adapted to meet the present case.

One interpretation (suggested by Revusky's, 1971, analysis) is that an association may be formed between the response and its immediate consequence (the signal); and the signal, by virtue of its association with food, will be able to act as a conditioned reinforcer for the responses that precede it. Responding could thus be maintained by a response–signal association, conceivably at a higher level than could be supported by the weak response–reinforcer association formed when no signal is presented. The other possibility is that the stimulus inserted in the delay-of-reinforcement interval has its effects not by virtue of the associations it forms itself but because it promotes the formation of a strong direct association between the target event and the reinforcer. According to Rescorla's (1982) version of this suggestion (see also Lett, 1982; Lieberman, McIntosh, & Thomas, 1979), such a stimulus "catalyzes" the formation of the association, perhaps by enhancing the salience of the target event and thus ensuring that some representation of it survives the delay.

Rescorla (1982) has suggested an experimental design that might allow choice between these rival accounts (conditioned reinforcement and catalysis) of potentiation. He applied it to an investigation of the mechanism by which a signal intervening between a target keylight and food acts to

potentiate autoshaped responding to the target in pigeons. Pigeons were trained with two keylight stimuli (A and B), each followed on 50% of presentations by delayed reinforcement. Each was also followed on some trials by the immediate presentation of a third keylight stimulus (X). For stimulus B, X occurred only on nonreinforced trials, whereas for A it occurred only on reinforced trials, filling the gap between the offset of A and the presentation of food. This procedure allows the formation of an X–food association, but since X occurs equally often after A and after B, any conditioned reinforcing effect it exerts cannot produce differences in response rate to stimuli A and B. Catalysis, however, will occur only when X bridges the gap between the target stimulus and the reinforcer and thus should promote responding to A but not to B. The details of the results of this experiment are not of immediate concern here (they suggested the operation of catalysis [but see also Honey, Schachtman, & Hall, 1987]). Our interest in it is that the design can be adopted in modified form so that it can be applied in the training procedure used by Schachtman et al. (1987). It should then allow us to decide between conditioned reinforcement and catalysis as explanations for the potentiation effect seen in the instrumental responding of pigeons trained with the signaled 3-s delay of reinforcement.

## EXPERIMENT 1

Pigeons were trained on a free-operant multiple schedule having three components (trial types), each associated with a different color of response key. In each, responding was reinforced according to a VI schedule with a 3-s interval occurring between the effective response and the delivery of food. Following Schachtman et al. (1987) one component constituted a signaled condition in which the 3-s interval was filled by the illumination of the houselight, whereas in a second component (the no-signal condition) the houselight was not used. Comparison of performance in these two conditions in the experiment by Schachtman et al. (1987) revealed the potentiation effect—a higher response rate in the signaled than in the no-signal condition. The third type of trial included in the present experiment constituted an uncorrelated condition. Response-contingent presentations of the houselight occurred as in the signaled condition but did so according to a schedule independent of that determining the delivery of food.

In the Schachtman et al. (1987) study the houselight signal was perfectly correlated with food. The addition of the uncorrelated condition to the present experiment means that the signal will be followed by food on only 50% of presentations. It might nonetheless acquire some conditioned reinforcing properties, and if these properties are responsible for the potentiation effect an elevated response rate can be expected in both of the conditions in which the signal occurs. The effect may be reduced in magnitude compared with that demonstrated by Schachtman et al. (1987)

but potentiation should occur to the same degree in both the signaled and the uncorrelated condition. If the signal acts as a catalyst, however, there should be a difference between the two conditions. Only in the signaled condition does the light bridge the gap between the response and the reinforcer and, thus, only in this condition can potentiation be expected.

In a final stage of training, uncorrelated presentations of the houselight were discontinued so that the subjects experienced only the signaled and the no-signal conditions. This stage allowed the possibility of replicating the basic potentiation effect of Schachtman *et al.* (1987).

*Method*

*Subjects.* The subjects were eight locally obtained pigeons maintained throughout the experiment at 80% of their *ad lib* body weights. They had previously served in a series of studies using the autoshaping procedure but had no previous experience of operant schedules. Their autoshaping experience included training with the colored keylights to be used in this experiment, sufficient to establish a high rate of response to each of these colors.

*Apparatus.* A three-key operant chamber measuring $30 \times 30 \times 30$ cm was used. On one wall were three translucent response keys, each 2 cm in diameter and positioned 20 cm above the floor. These could be illuminated from behind with red, blue, green, or white light. Below the central key at floor level was an aperture giving access to a grain feeder that was operated for 5 s to supply reinforcement. A houselight consisting of a 3-W bulb that could be operated at 24 V was fixed centrally in the ceiling of the chamber. This light was turned off except when being used to supply the signal. The chamber was enclosed in a sound-attenuating box containing a ventilating fan that provided some background noise.

*Procedure.* The birds needed little pretraining given their previous experience of autoshaping. They received four 40-min sessions in which one key was lit continuously with white light. For the first two sessions the center key was used; thereafter, and for the rest of the experiment, only the right key was used. A VI 30-s schedule was in force for the first of these sessions and a VI 60-s schedule was in force for the rest. Over the next three sessions, responding to colored keylights was established. Each session consisted of 24 trials, 8 each for the three key colors, red, blue, and green. Trials were 90 s in duration and there was a 10-s interval between trials during which the chamber was dark. The ordering of trials was determined by a quasirandom sequence that allowed no more than 2 trials of the same type to occur consecutively and that was changed from one day to the next. The VI 60-s schedule was in force during all trials and there was no delay of reinforcement.

The procedure for stage 1 of the experiment was identical to that just

described except that a 3-s delay of reinforcement was imposed in the presence of all the key colors. The houselight was illuminated during the delay on green-key trials (the signaled condition). During blue-key trials (the uncorrelated condition), response-contingent presentations of the 3-s houselight occurred according to a second VI 60-s schedule that operated independently of that determining the delivery of food. The houselight was not presented during red-key trials (the no-signal condition). During the delay-of-reinforcement intervals the timers controlling the length of the trial and the VI schedules continued to run, but responses were without programmed consequences. Responses occurring during these intervals did not count toward the total. Training continued for 20 sessions.

In the second stage of training, uncorrelated presentations of the house-light no longer occurred in the presence of the blue keylight; in other respects conditions remained as before. Stage 2 continued for 40 sessions.

*Results*

During preliminary training the subjects responded equally readily to each of the key colors. On the final pretraining session the group mean response rates were 59.77 responses per min (rpm) to the red, 59.43 rpm to the blue, and 56.75 rpm to the green. An analysis of variance comparing response rates in the three trial types showed that there was no significant difference among them ($F < 1$). Differences developed, however, when the colors were associated with differing contingencies.

Figure 1 shows group mean response rates (reduced to two-session blocks) for stage 1 in each of the three conditions. There was apparently an initial decline in response rate from the levels observed in pretraining, a consequence, presumably, of the introduction of the 3-s delay of reinforcement. But after the first three training blocks, responding recovered to some extent and stable rates were established that differed from one condition to another. The lowest rate was recorded in the signaled condition, the highest in the uncorrelated condition. The no-signal condition generated a response rate between these extremes, although, by the end of training, the difference between this and that seen in the uncorrelated condition was slight. A two-factor analysis of variance with condition (trial type) and session block as the factors showed that there was a significant difference among the conditions, $F(2, 14) = 8.61$, $p < .01$. Despite the impression given by the figure, the effect of blocks was not significant, $F(9, 63) = 1.02$, nor was the interaction between the two factors, $F < 1$. Applying Tukey's HSD test to group mean scores collapsed over all trials for each condition revealed that the signaled condition differed significantly ($p < .01$) from the uncorrelated condition but that the no-signal condition did not differ from either of the other two ($ps > .05$).

Figure 2 shows the group mean response rates recorded in the presence of each key color over the 10 four-session blocks of stage 2. It is apparent
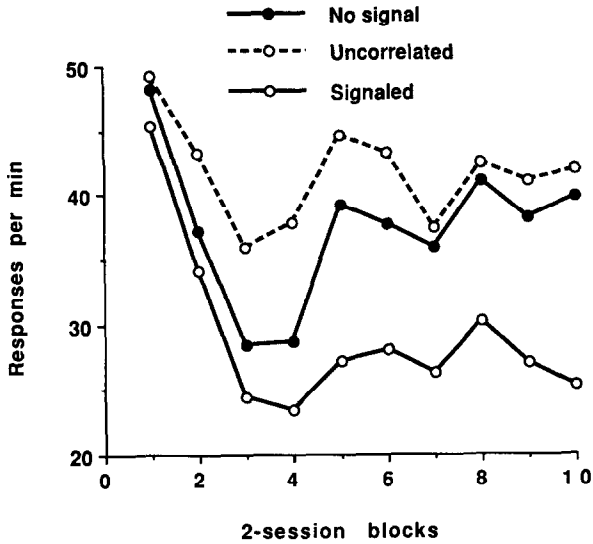
FIG. 1. Group mean response rates in stage 1 of Experiment 1 for pigeons responding on a VI schedule with a 3.0-s delay of reinforcement. Different keylight colors were associated with the signaled condition (in which the houselight was lit during delay intervals), the uncorrelated condition (in which houselight presentations were determined by a separate VI schedule), and the no-signal condition (in which no presentations of the houselight occurred).
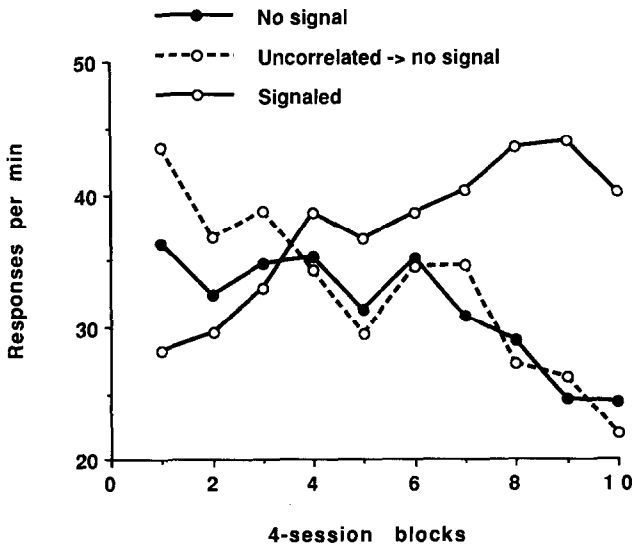


FIG. 2. Group mean response rates in stage 2 of Experiment 1. Presentations of the houselight no longer occurred in the presence of the key color that in stage 1 had been associated with the uncorrelated condition; other conditions remained as in stage 1.

that performance initially reflected the differences evident at the end of the previous stage, with the rate in the signaled condition being lower than that shown in the other two conditions. Changes in response rate occurred slowly but by the end of training, partly as a consequence of an increase in the signaled condition and partly as a consequence of a decrease in rate in the other two conditions, the situation was reversed with the signaled condition showing the highest response rate.

The data for Fig. 2 were subjected to an analysis of variance with condition and session block as the factors. There was no significant main effect of condition ($F < 1$) or of block, $F(9, 63) = 1.56$, but the interaction between the factors was significant, $F(18, 126) = 5.45, p < .01$. Analysis of simple main effects showed that there were reliable differences among the conditions on block 8 ($F = 3.81, p < .05$), block 9 ($F = 5.54, p < .01$), and block 10 ($F = 4.79, p < .01, df = 2203$ for all comparisons). On all other blocks $F < 1$, except for block 1 where $F = 2.78$. Tukey's HSD tests showed that on each of the final three blocks the response rate in the signaled condition differed reliably ($p < .05$) from that shown in either of the two no-signal conditions, which did not differ one from another.

Finally, in order to allow a direct comparison between the two stages of training, an additional analysis was conducted on the data for the last session block of each stage. There was no significant overall effect of stage, $F(1, 7) = 4.63$, and no significant effect of condition ($F < 1$), but there was a significant interaction between the factors, $F(2, 14) = 7.70$, $p < .01$. Analysis of simple main effects showed that there was no significant change from the end of stage 1 to the end of stage 2 in the performance shown in the presence of the red keylight (associated with the no-signal condition in both stages), $F(1, 7) = 4.49$. The decline in rate in the presence of the blue keylight (associated with the uncorrelated condition in stage 1 but with no signal in stage 2) was significant, $F(1, 7) = 11.64, p < .05$, as was the increase in the presence of the green (associated with the signaled condition in both stages), $F(1, 7) = 5.58$, $p < .05$.

*Discussion*

The final stage of this experiment confirmed the reliability of the potentiation effect reported by Schachtman *et al.* (1987). Inserting a signal in a 3-s delay between the effective response and the delivery of food generated a higher rate of response than that observed when no signal was presented. The new results come from the first stage of training in which the subjects experienced not only the signaled condition but also one in which the event used as the signal occurred equally often but uncorrelated with reinforcement. This procedure resulted in a marginally

higher rate in the uncorrelated condition than in that with no signal and a much lower rate in the signaled condition.

This pattern of results is quite different from what would be expected if the potentiation effect depended on a process of catalysis (Rescorla, 1982). According to this account, potentiation should occur when the signal bridges the interval between the response and the reinforcer, regardless of the fact that the signaling event is occurring elsewhere uncorrelated with reinforcement. Other things being equal, the uncorrelated condition should not differ from the no-signal condition, but the signaled condition should generate a higher rate than either. Neither of these predictions is supported by the data. The signaled condition generated only a low response rate in stage 1, whereas uncorrelated presentations of the signal tended to elevate response rate (as shown by the fact that removing the signal in stage 2 resulted in a significant decline in rate).

The suggestion that the potentiation effect depends on the conditioned reinforcing power of the signal fares a little better. The effect of introducing uncorrelated presentations of the signal would be to limit the growth of such power. Accordingly, the enhancement in rate engendered by having the signal present might well be only a small effect but it should still occur and should do so to the same extent in both of the conditions in which the signal is presented. The results found in the uncorrelated condition itself, then, were what this interpretation might have expected; however, without the addition of new assumptions, there is no reason to expect that the rate in the signaled condition should be significantly lower than that seen in any other condition. If this theory is to be retained, it is necessary to specify what other factors are at work in this situation and how they come to result in such a low rate in the signaled condition. The next experiment investigates some possibilities.

## EXPERIMENT 2

If a signal inserted in a delay-of-reinforcement interval acquires strength as a conditioned reinforcer then, we may assume, it will also acquire the power to elicit overt classically conditioned responses. One of the determinants of the effect of such a signal on measured response rate, therefore, will be the relationship between the response directly elicited by the signal and that measured by the experimenter (see, e.g., Iversen, 1981). In Experiment 1, for instance, any autoshaped tendency to approach the houselight used as the signal would tend to reduce the rate of keypecking. The fact that primary reinforcement would then occur at a time when the subject was engaged in some behavior other than keypecking might act to magnify this effect by increasing the likelihood of behavior that competes with the keypecking response.

Although it is unlikely to be the only mechanism by which the signal acts to lower response rate (see Roberts, Tarpy, & Cooney, 1985), there

is some evidence that competition between responses does play a role (Reed, Schachtman, & Hall, 1988a). However, if we accept the possibility that competing responses evoked by the signal contribute to the low level of responding seen in the signaled condition of Experiment 1, then it remains to be explained why this effect should have been found only in stage 1 of that experiment. Why should the effect be evident only when the subjects are given concurrent experience of uncorrelated presentations of the signal?

One possibility emerges when we consider the implications of the fact that including uncorrelated presentations means that reinforcement for the signal will be partial. Although a partial schedule is likely to endow the signal with less associative strength than would a continuous schedule, the ability of the signal to elicit responses that would compete with key-pecking may be increased. It is well established for pigeon autoshaping (e.g., Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980) that partial supports higher levels of responding than does continuous reinforcement, an effect that appears to occur because a partially reinforced stimulus continues to evoke orienting behavior when a continuously reinforced one does not (Collins & Pearce, 1985; Honey *et al.* 1987; Pearce, Kaye, & Collins, 1985). Partial reinforcement for the signal, then, will increase the likelihood that subjects will engage in signal-directed responding, reinforcement of this competing behavior will be especially likely, and a low rate of keypecking can therefore be expected in the signaled condition.

According to the account just offered, the overshadowing effect observed in stage 1 of Experiment 1 occurs because the signal tends to evoke behavior that is incompatible with keypecking. We may test this suggestion, therefore, by using as the signal some stimulus displayed on the key itself. Such a stimulus would not evoke a competing response but autoshaped keypecking and thus there should be no overshadowing effect in this case. Indeed, this procedure, by arranging for the possibility that a relatively high rate of (autoshaped) keypecking will precede primary reinforcement, might result in an enhancement in the overall response rate.

To investigate this prediction pigeons in Experiment 2 received training on a multiple schedule having four components, each associated with a different key color. In the presence of one color the 3-s delay-of-reinforcement interval was signaled by the illumination of the houselight (the H-S condition), and in the presence of a second key color the houselight occurred according to a VI schedule independent of that controlling the availability of food (the H-U condition). Performance on these two types of trial should match that shown in the signaled and uncorrelated conditions of stage 1 of Experiment 1, with the rate in H-U being higher than that in H-S. The second two components again constituted signaled and uncorrelated conditions but in these a pattern of lines superimposed on the key was used as the signal. It was anticipated that this signaled

condition (K-S) would not result in a low rate of responding immediately prior to primary reinforcement and that as a consequence the overall rate should be no lower than that seen in the comparable uncorrelated condition (K-U). Indeed, if the rate in the presence of the signal in K-S is especially high, then the overall rate in K-S might well be higher than that in K-U.

## Method

An additional 10 pigeons served as subjects. They were maintained as in Experiment 1. These birds had previously served in a study using the autoshaping procedure but had no previous experience of operant schedules or of the keylight stimuli used in the present experiment. After initial pretraining in which keypecking to a white key was established they were trained over the course of four sessions to peck on a VI 60-s schedule at the four key colors, red, blue, green, and orange. Each session consisted of 24 trials, 6 each for each of the colors.

The procedure for the critical phase of the experiment was identical to that just described except that the 3-s delay of reinforcement and the signals were introduced. In the presence of orange the delay was filled by illumination of the houselight (the H-S condition); in the presence of blue, uncorrelated presentations of the houselight occurred (H-U). The red key was associated with the K-S condition, the delay interval being signaled by a grid of three vertical and three horizontal lines superimposed on the key color. The lines were 2 mm wide and spaced 2 mm apart. In the K-U condition, associated with the green key, presentations of the grid stimulus were determined by a separate VI schedule. Details not specified here were the same as those described for Experiment 1.

## Results and Discussion

The subjects responded equally readily to each of the key colors during the pretraining stage although, presumably as a consequence of their more restricted preexperimental experience, at a generally lower rate than that shown by the birds in Experiment 1. On the final pretraining session the mean rates were 31.99 rpm in orange, 32.26 rpm in blue, 35.78 rpm in red, and 35.12 rpm in green. An analysis of variance showed that there was no significant difference ($F < 1$) among these scores.

Figure 3 shows in two-session blocks the group mean response rates that developed when the houselight and keylight signals were introduced. The results for the H-S and H-U conditions replicate the essential findings for the equivalent groups of Experiment 1 (stage 1). In that experiment, in which responding started from a much higher level, the difference was established chiefly by a decline in rate in the signaled condition, whereas in the present experiment it appears that the houselight signal has its effect by limiting any increase in rate. In both cases, however, the presence
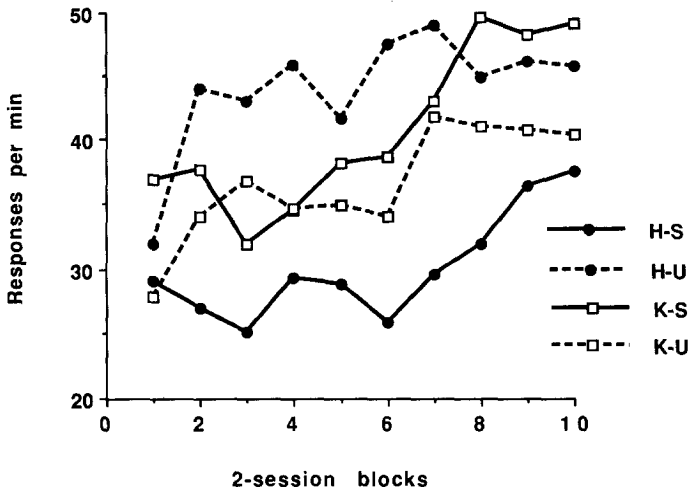
FIG. 3. Experiment 2: Group mean response rates for pigeons responding on a VI schedule with a 3.0-s delay of reinforcement. Different keylight colors were associated with each of four conditions. In the two signaled conditions (S), the delay interval was filled either by the illumination of the houselight (H) or by the presentation of a pattern on the key (K). In the uncorrelated conditions (U), the presentations of these events were determined by separate VI schedules.

of a houselight signal prior to food delivery resulted in a lower overall rate of response than that seen in the condition in which houselight and food were uncorrelated. No such effect was seen in the conditions having the signal superimposed on the key; if anything, by the end of training the rate in the signaled condition (K-S) was higher than that in the uncorrelated condition (K-U). A two-factor analysis of variance conducted on the data summarized in Fig. 3 showed that there was a significant effect of block, $F(9, 81) = 3.32$, $p < .01$, a significant difference among the conditions, $F(3, 27) = 6.56$, $p < .01$, and a significant interaction between these two factors, $F(27, 243) = 2.09$, $p < .01$. In order to facilitate interpretation of this interaction, a separate two-factor analysis was conducted on the data from the H-U and H-S conditions. This yielded a significant effect of block, $F(9, 81) = 2.06$, $p < .05$, a significant effect of condition, $F(1, 9) = 17.69$, $p < .01$, and a significant interaction between the two factors, $F(9, 81) = 3.77$, $p < .01$. An equivalent analysis conducted on the data for the K-U and K-S conditions revealed only a significant effect of block, $F(9, 81) = 4.22$, $p < .01$; there was no effect of condition ($F < 1$) and no significant interaction between the factors, $F(9, 81) = 1.20$.

Thus, the overshadowing effect of the signal was successfully replicated when the houselight was used as the signal, and using the keylight as the signal abolished this effect, although it did not convert it into reliable

potentiation. The failure to find an effect with the keylight is not to be attributed to a lack of salience on the part of that stimulus for two reasons. First, there is evidence from other experiments on signaled delay of reinforcement in pigeons that a pattern of lines superimposed on a colored key can, in certain conditions of training, be just as effective as a houselight signal in modifying overall response rate (Hall et al., 1987, Experiments 1 and 2). Second, monitoring the responses emitted during the delay interval in the present experiment showed that the keylight was perfectly effective in modifying local response rate.

Responding during the delay interval was recorded on the last block of training, separately for each of the four trial types. The presence of the keylight during this interval tended to elevate responding; the mean number of responses per delay interval was 6.51 in condition K-S and 2.91 in condition K-U. The houselight signal on the other hand tended to suppress responding; the equivalent means for conditions H-S and H-U were 2.33 and 3.66. A factorial analysis of variance showed that there were significant effect of the type of event used as the signal $F(1, 9) = 11.98$, $p < .01$, no significant main effect of whether the signal was correlated or uncorrelated, $F(1, 9) = 3.65$, and a significant interaction between the factors, $F(1, 9) = 20.71$, $p < .01$. A simple main effects analysis showed that the two conditions in which the houselight was presented (H-S and H-U) did not differ significantly, $F(1, 9) = 2.38$, but that there was a significant difference between the conditions K-S and K-U, $F(1, 9) = 23.47$, $p < .01$. (It may be noted that the rates in the delay intervals on which no signal occurred are substantially higher than the overall response rates. Such an outcome is to be expected if, as seems likely, although we have no data to confirm it, the responding of the birds on these schedules takes the form of bursts of pecking with relatively long interburst pauses).

These results are thus consistent with the suggestion that the pattern of behavior that occurs just before primary reinforcement in this procedure might play a role in determining the overall response rate for a give trial type. An overshadowing effect (comparing signaled and uncorrelated conditions) is evident when the signal is a houselight that tends to suppress keypecking prior to food delivery in the signaled condition. However, there is no overshadowing (and some sign of potentiation) when the signal is one that ensures that the rate of keypecking will be high prior to food delivery.

## GENERAL DISCUSSION

Pigeons that experience a 3-s delay of reinforcement on a VI schedule will respond at a higher rate when a signal (illumination of the houselight) fills the interval than in a condition in which no signal occurs (Experiment 1, stage 2). This potentiation effect does not occur when the birds ex-

perience concurrently a condition in which 3-s presentations of the house-light occur uncorrelated with reinforcement. This result appears to con-tradict the suggestion that the potentiating effect depends on its ability to catalyze the formation of an association between response and food—there is no reason why such an ability should be lost because uncorrelated presentations of the houselight occur during another type of trial. The suggestion that the signal produces potentiation because it ensures im-mediate conditioned reinforcement for responding does allow that the introduction of the uncorrelated condition might modify the size of the potentiation effect. The reduced reliability of the houselight as a predictor of reinforcement can be expected to result in a lower associative strength and thus reduce the extent of its conditioned reinforcing power. What is not to be expected, however, is that the rate of response in the signaled condition should turn out to be markedly less than that seen in either the no-signal condition or the uncorrelated condition (Experiment 1, stage 1).

A possible source of this last effect is that partial reinforcement for the signal (a consequence of including the uncorrelated condition) might en-sure that signal-directed behavior is particularly vigorous and that primary reinforcement of this behavior establishes powerful competing responses when the signal is a houselight. This suggestion was investigated in Ex-periment 2 in which it was demonstrated that the signaled condition pro-duced a somewhat higher rate than the uncorrelated condition when the signal was located on the key and thus unlikely to generate responses that competed with keypecking. The notion that the outcome of these experiments may depend in part on the behavior that the signal itself comes to elicit does not directly contradict the view either that the signal acts also as a catalyst or that it acts as a conditioned reinforcer. It sits somewhat more easily with the latter view, however, if only because the ability of the signals in these experiments to evoke responding is taken to a consequence of their association with food. Once it is allowed that such an association is formed and is effective then it follows that the signal is likely to have conditioned reinforcing properties and that these prop-erties might well be enough to generate potentiation when conditions are such as to maximize their effects (i.e., when the correlation between signal and food is perfect).

Finally, it is appropriate to comment on the relationship between the potentiation effect under study here and the seemingly similar effects that have been found in studies of free-operant responding in rats. The ex-perimental designs used with rats have been different (usually comparisons have been between-subject), the delay interval and signal have been much briefer (routinely 500 ms), but with some schedules (e.g., variable ratio: Reed, Schachtman, & Hall, 1988b; differential reinforcement of high rate: Reed, 1989a) the presence of the signal has been shown to elevate the

rate of responding. The interpretation offered for these potentiation effects (see also Reed, 1989b) was that the signal acts to "mark" in memory (Lieberman et al., 1979) the burst of high frequency responding that tended to precede it on these schedules, ensuring that this pattern of behavior received particularly effective reinforcement.

It seems unlikely that such marking could play a major role in producing the potentiation observed with the procedures used here—VI schedules tend to generate low rates of responding with many long interresponse times, and to mark such a pattern of behavior might tend to reduce rather than enhance the overall rate of response. Thus, marking could contribute to the overshadowing effect (when it occurs) but, on the face of things, it could hardly be responsible for the potentiation seen with a VI schedule. We should acknowledge, however, that if the unsignaled delay of reinforcement were so long that the reinforcer was quite ineffective in strengthening the required response, then even a low rate acquired as a consequence of marking might be superior. We have attributed the basic potentiation effect to conditioned reinforcement; however, if the unsignaled 3-s delay used here approaches the limiting case just described, then a contribution from a marking process cannot be ruled out.

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