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CONDITIONED SUPPRESSION AND CONDITIONED ENHANCEMENT WITH THE SAME POSITIVE UCS: AN EFFECT OF CS DURATION[1]

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Previous experiments have shown that positively reinforced operant responding is suppressed during a conditioned stimulus terminated with an electric shock (conditioned suppression). In the present experiment, the conditioned stimulus was terminated with a positive unconditioned stimulus, and it was found that the duration of the conditioned stimulus was a key factor in determining whether response suppression or response enhancement was observed during the stimulus. The lever-pressing responses of rats were maintained by a variable-interval schedule of food reinforcement. While the rats were pressing the lever, a light was occasionally turned on, its offset coincident with a brief period of access to a sucrose solution. In consecutive blocks of sessions, the light duration was 40 sec, 12 sec, or 120 sec. Results showed that the rate of lever pressing was substantially suppressed during the 12-sec stimulus, slightly suppressed during the 40-sec stimulus, and enhanced during the 120-sec stimulus.

One characteristic that differentiates operant and respondent conditioning is the experimenter's criterion for delivering reinforcement. In operant conditioning, the delivery of reinforcement is response-contingent, but in respondent conditioning, the delivery of the unconditioned stimulus (UCS) is dependent only on the presentation of the conditioned stimulus (CS). Rather than studying operant and respondent conditioning procedures separately, a number of investigators have designed experiments to explore the interaction of the two procedures. Typically, the purpose of these experiments has been to observe any change in the rate of operant responding during a concurrently presented CS.

For example, experiments have demonstrated that established, food-reinforced operant responding is suppressed during a CS terminated with electric shock (*e.g.*, Estes and Skinner, 1941; Kamin, 1965). Stein, Sidman, and Brady (1958) showed that one of the parameters affecting the degree of response suppression was the duration of the CS. At long CS durations, response suppression was relatively slight, but when CS duration was short, response suppression was almost complete. The experimenters said that at least one reason for such a relationship was that the subject would have missed more reinforcements by suppressing during a long CS than during a short CS.

Other investigators have studied a directly comparable paradigm in which a CS terminated with a positive UCS was presented while a subject was responding for contingent positive reinforcement. Herrnstein and Morse (1957) reported one such experiment in which pigeons were differentially reinforced for responding at low rates. The rate of food-reinforced operant responding was enhanced in four out of six pigeons during presentations of a CS that preceded non-contingent food delivery. Azrin and Hake (1969) suggested that the enhancement of operant responding during the CS might be accounted for by the similarity between the response-contingent reinforcer and the UCS. Consistent with this claim, they reported that operant responding was suppressed during the CS when the reinforcement and the UCS were either qualitatively or quantitatively different.

The similarity of the two reinforcers, however, may account only partly for the enhanced response rate during the CS reported by Herrnstein and Morse (1957). Other relevant evidence comes from an experiment by Brady (1961), who used a procedure similar to that of Azrin and Hake (1969). Brady found that the rate of water-reinforced operant responding of a rat was enhanced during a CS terminated with electrical stimulation in the septal region of the brain. Thus, Brady's re-

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sults showed that enhanced response rates occur during the CS even when the response-contingent reinforcer and the UCS are different.

An important difference between the Azrin and Hake (1969) procedure and that used by Brady (1961) was the duration of the CS. Azrin and Hake used a 10-sec CS that produced response suppression; Brady used a 5-min CS that produced response enhancement. These different results may represent a phenomenon comparable to the attenuation of conditioned suppression as CS duration increases. If a similar effect of CS duration exists when the CS is terminated with a positive UCS it would explain the differences between the Azrin and Hake (1969) and the Brady (1961) experiments. The present experiment investigated this possibility.

METHOD

Subjects

Five male hooded rats of the Long-Evans strain, 120 days old, were obtained from Perfection Breeders, Inc., Douglassville, Pa. After five days of free access to a diet of Purina Laboratory Chow and water, the rats were placed on a 23-hr food deprivation schedule that was maintained throughout the experiment. Water was freely available in the home and feeding cages.

Apparatus

The rats were tested in a standard operant conditioning chamber with interior dimensions 8.75 by 7.5 by 7.5 in. (22.2 by 19.1 by 19.1 cm). The front wall of the chamber had a response lever 1.25 in. (3.2 cm) to the right of center and 2.5 in. (6.4 cm) above the floor, a dry-food hopper adjacent to the right wall 0.375 in. (1.0 cm) above the floor, and an opening for liquid reinforcement access 0.75 in. (1.9 cm) above the floor and 1.75 in. (4.4 cm) from the left wall. A light was located 5.5 in. (14.0 cm) above the liquid reinforcement opening. The chamber was housed in a ventilated ice chest that served as a sound attenuator. In addition, masking white noise was delivered into the experimental room. Conventional relay equipment, located in an adjacent room, scheduled stimulus events and recorded responses.

Procedure

The rats were tested daily in 60-min experimental sessions. During the first two sessions, each lever press was reinforced with a 45-mg Noyes food pellet delivered into the dry-food hopper. During Sessions 3 to 5, the response-contingent reinforcement was delivered on a VI 1-min schedule, and beginning with Session 6 on a VI 2-min schedule. The VI 2-min schedule was maintained for the duration of the experiment.

Beginning with Session 22, each rat received six presentations per session of a light CS paired with 6-sec access to 0.5 cc of a sucrose solution delivered to the liquid reinforcement opening. Access to the sucrose solution began when the CS was terminated. The interval between consecutive sucrose presentations varied with a mean of 10.5 min and a range of 5 to 18 min. Neither the CS nor access to the sucrose solution was contingent on the rat's behavior.

The duration of the CS was varied for each rat in consecutive blocks of sessions according to the schedule shown in Table 1. Since the schedule of sucrose presentations was constant across sessions, the variation in CS duration produced an inverse variation in the mean interval between a sucrose presentation and the next CS onset. The concentration of the sucrose solution was 25% by weight except during Sessions 22 to 42 (Sessions 22 to 34 for Rat-4) when the sucrose concentration was 10%.

Table 1

Schedule of sessions for each rat at the indicated CS duration.

CS Duration (sec)	*Sessions*				
	R-1	*R-2*	*R-3*	*R-4*	*R-5*
40	22-69	22-69	22-69	22-60	22-69
120	70-90	70-90	70-90	61-81	70-90
40	91-117	91-117	91-117	82-108	91-117
12	118-141	118-141	118-141	109-123	118-141
6	—	—	—	—	142-165
40	142-162	142-162	142-162	—	166-180
120	—	—	—	—	181-201

RESULTS

The effect of the CS-sucrose pairings on response rate was determined using the inflection ratio $B/(A + B)$, where B represents the response rate during the CS and A represents

the response rate in an equal interval preceding CS onset (pre-CS). The ratio can vary between the limits 0.00 and 1.00, with a ratio of 0.50 indicating identical response rates in the pre-CS and CS periods. A ratio greater than 0.50 indicates that the response rate was higher during the CS than during the pre-CS period, an outcome that will be referred to as an enhancement of response rate. A ratio less than 0.50 indicates that the response rate was lower during the CS than during the pre-CS period, an outcome that will be referred to as response suppression.

The mean inflection ratios for consecutive three-session blocks are shown in Fig. 1 as a function of the CS duration. All rats showed response suppression during the last nine sessions of exposure to the 12-sec CS and response enhancement during exposure to the 120-sec CS. The 40-sec CS produced mixed results. R-1, R-3, and R-4 showed a suppression of responding during each exposure to the 40-sec CS. R-2, however, suppressed its rate during the second and third exposures to the 40-sec CS and enhanced its response rate during the first exposure. R-5 showed response suppression during the first and second exposures and response enhancement during the third exposure. Thus, the general effect of the 40-sec CS was a mild suppression of responding.

The response suppression of R-1, R-2, R-3, and R-4 was considerably greater in the 12-sec CS than in the 40-sec CS, but R-5 showed little difference in suppression at these two CS durations. The 6-sec CS produced a level of response suppression for R-5 that was greater than the level observed in the 40-sec CS.

Because the inflection ratio does not show how the pre-CS rate was affected by the CS-UCS pairing procedure, and because it does

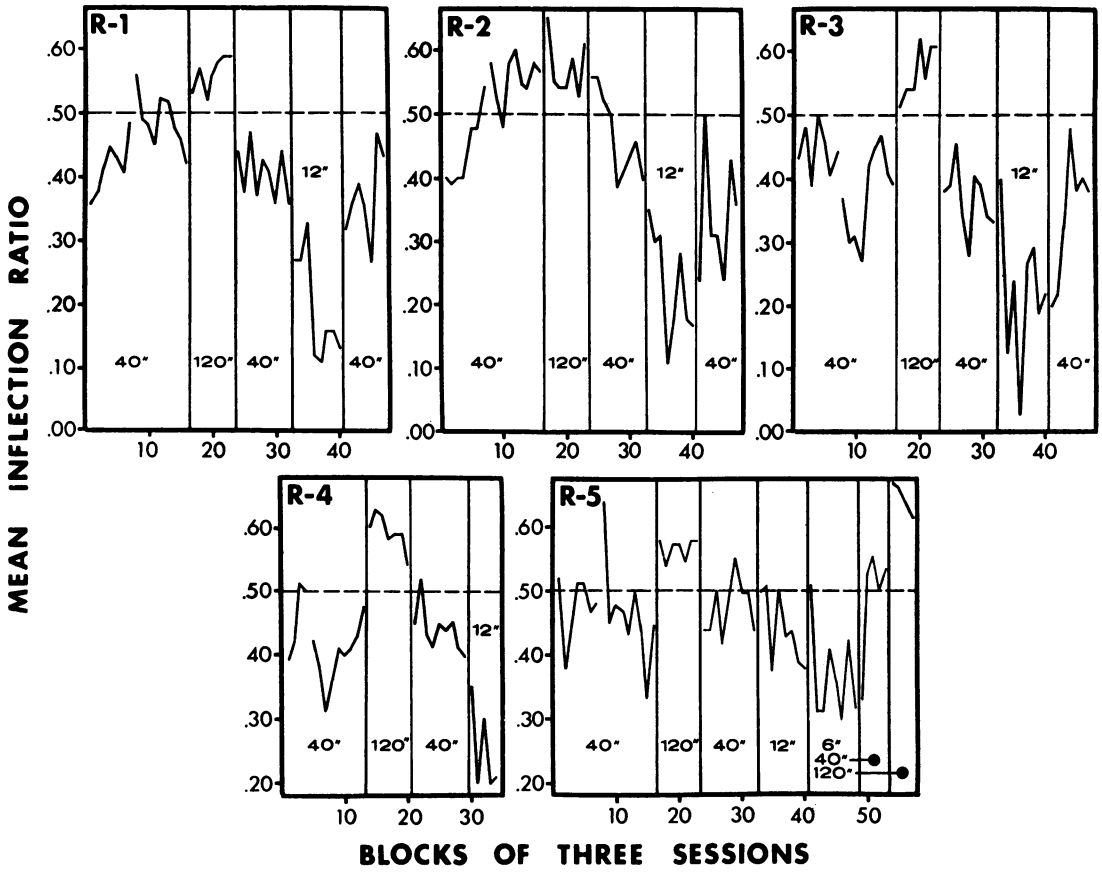

Fig. 1. Changes in the mean inflection ratio as a function of the CS duration. Each graph is for a different rat. Baseline response rate is the rate of lever pressing in the period immediately preceding the CS. Ratios greater than 0.50 represent response facilitation in the CS, and ratios less than 0.50 represent response suppression in the CS.

not provide information regarding the absolute response rates in the pre-CS and CS periods, the following additional measures were computed. First, response rates were recorded in sham pre-CS periods during the five sessions preceding the start of CS-UCS pairings. The mean rate during the sham pre-CS periods (P rate) is shown for each rat in Fig. 2. Figure 2 also shows the mean pre-CS and CS response rate for each rat during the last nine conditioning sessions at each CS duration.

None of the rats' P response rates were stable, and after CS-UCS pairings started, pre-CS response rates continued to rise above the P rates for several sessions. There is no basis for deciding whether this pre-CS rate increase was caused by the introduction of CS-UCS pairings or was due simply to additional experience with the VI schedule of reinforcement. As conditioning progressed, however, the pre-CS response rate fell to a level well below the P response rate and the reduction was generally maintained across all CS durations. R-5 was the only rat whose pre-CS response rate ever reached or exceeded its P response rate, and then only when the CS durations were 12 and 6 sec. This analysis indicates, then, that the CS-UCS pairings were usually accompanied by a decreased pre-CS response rate.

Figure 2 also shows that for R-1 through R-4, the change in CS duration affected primarily the CS response rate rather than the pre-CS response rate. There was a tendency for the pre-CS rate to increase slightly across

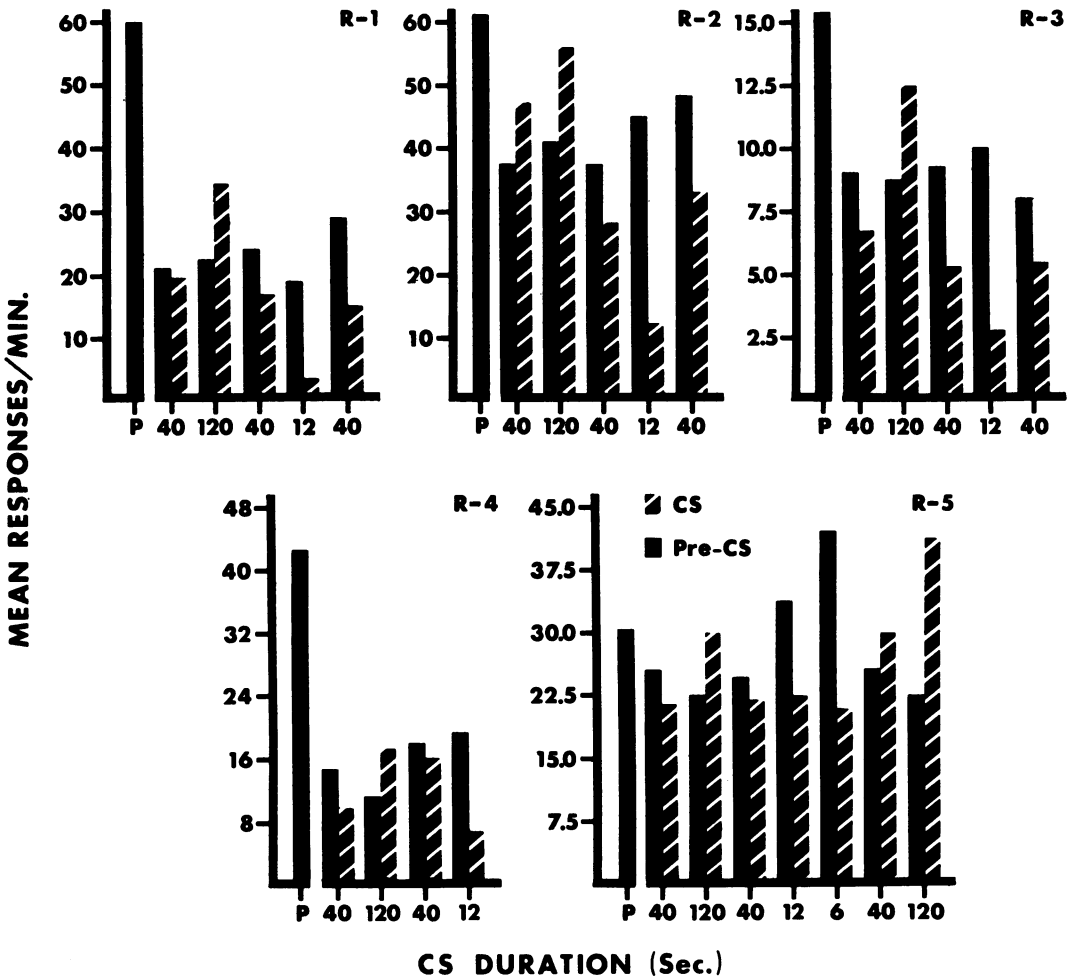

Fig. 2. Each rat's mean responses per minute in pre-CS and CS periods for the last nine sessions at the indicated CS duration. Also included is each rat's mean responses per minute in sham pre-CS periods (P) during the five sessions before the start of CS-UCS pairing.

sessions, but the increase was small compared to the change in the CS response rate that occurred as a function of CS duration. The pre-CS rate of R-5, however, did increase during the sessions in which the CS duration was 12 and 6 sec. Thus, the decrease in the inflection ratio (see Fig. 1, R-5) as the CS duration decreased from 40 sec to 6 sec was almost completely attributable to an increase in the pre-CS rate, rather than to a decrease in the CS rate. The response enhancement of R-5 during the second exposure to the 120-sec CS was produced by the combined effect of a decreased pre-CS response rate and an increased CS response rate.

It is interesting to note that response rates during the 120-sec CS did not exceed the P response rates except in the case of R-5's second exposure to this CS duration (see Fig. 2). In general, then, the response-rate enhancement observed during the 120-sec CS was not an enhancement above the level of responding before the start of conditioning.

Table 2

Percentage of Responses in the First Half of CS

CS Duration (sec)	*R-1*	*R-2*	*R-3*	*R-4*	*R-5*
6	—	—	—	—	60.1
12	85.4	94.7	77.4	77.0	65.6
40 (first exposure)	46.3	46.8	74.7	68.2	53.1
40 (second exposure)	53.1	47.8	73.4	69.5	48.6
40 (third exposure)	47.8	57.6	82.2	—	45.3
120 (first exposure)	43.2	46.6	49.7	51.3	45.8
120 (second exposure)	—	—	—	—	46.7

The distribution of responses within the CS was also examined. Table 2 presents each rat's responses in the first half of the CS expressed as a percentage of the total number of CS responses. Each entry represents the mean percentage for the last nine sessions at the indicated CS duration. It is clear that an increase in the CS duration produced a decrease in the percentage of responses during the first half of the CS. The 40-sec CS, however, had two different effects. R-1, R-2, and R-5 distributed their responses nearly equally in both halves of the 40-sec CS. R-3 and R-4 emitted most of their responses in the first half of the CS. This analysis showed that the rate of responding decreased during the course of the 12-sec CS, either remained constant or decreased during the 40-sec CS, and increased slightly during the 120-sec CS. The increased response rate during the 120-sec CS is similar to the pattern of increased responding during the CS reported by Herrnstein and Morse (1957) and to the pattern of responding that appeared in the cumulative records shown by Brady (1961).

These effects can be seen for individual rats in Fig. 3, which shows cumulative records of the lever presses of R-2 and R-5 during a terminal session at each CS duration. Each 40-sec record was taken during each rat's second exposure to the 40-sec CS. The records confirm that the increase in CS duration from 12 sec to 120 sec produced a transition from response suppression to response enhancement. They also show the typical patterns of CS responding described above. Note that the increase in response rate in the 120-sec CS was usually maintained until the UCS was presented.

Finally, the data were examined to see if there were any differences in reinforcement frequency as a function of CS duration. When total reinforcements per hour was measured with no differentiation between CS and non-CS time, the differences across CS durations were minor and inconsistent. Reinforcement frequency over the entire session always varied between 0.41 and 0.49 reinforcements per minute. Reinforcement frequency during the CS was calculated over the last nine sessions at each CS duration. All subjects except R-5 received fewer than 0.10 reinforcements per minute when the CS duration was 12 sec. This low reinforcement frequency reflected the high degree of response suppression during the 12-sec CS, but since all six 12-sec CSs in a session lasted for a total of only 72 sec, the total reinforcements per hour did not change to any significant degree. R-5 received 0.58 reinforcements per minute during the 12-sec CS and 0.46 reinforcements per minute during the 6-sec CS. The lowest reinforcement frequency recorded during the 40-sec CS was the 0.38 reinforcements per minute earned by R-4 during its first exposure. The highest reinforcement frequency recorded during the 40-sec CS was the 0.59 reinforcements per minute received by R-5 during its last exposure.

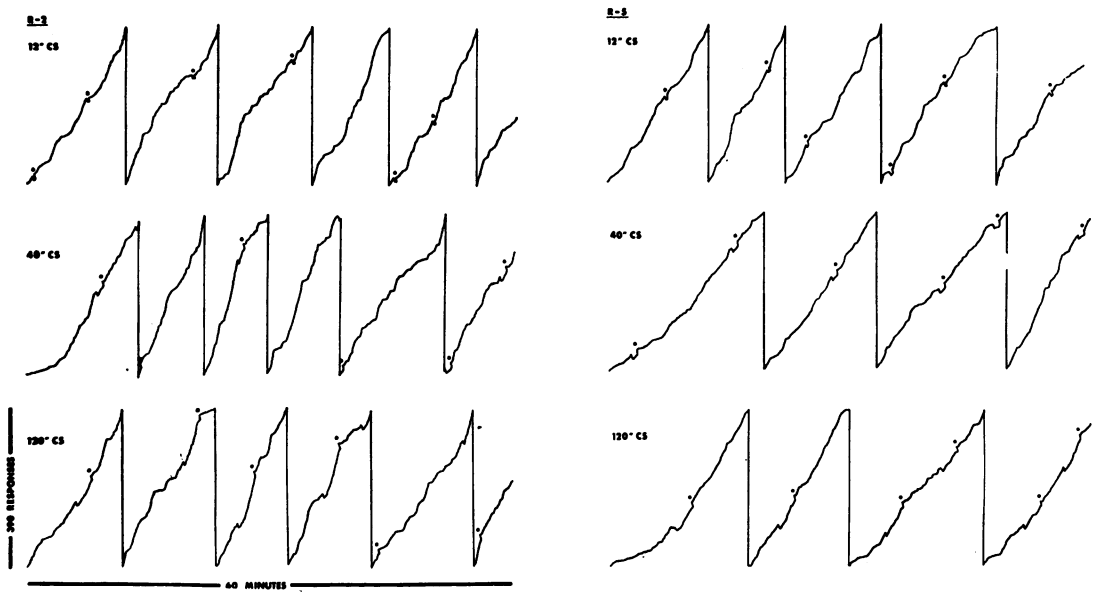

Fig. 3. Representative cumulative records of the lever-pressing responses of R-2 and R-5 during a terminal session at each CS duration. The response pen was deflected downward during the CS and was reset after 390 responses. A dot above the record indicates access to the UCS (sucrose solution) that occurred with CS termination.

When CS duration was 120 sec, R-4 received reinforcements at the lowest recorded rate—0.45 reinforcements per minute—and R-5 received reinforcements at the highest recorded rate—0.54 reinforcements per minute.

DISCUSSION

All five subjects showed the same pattern of response suppression at the short CS durations and response enhancement at the long CS duration. Azrin and Hake (1969) pointed out that many of the experiments on the operant-respondent interaction that demonstrated response enhancement used identical stimuli as the response-contingent reinforcer and the UCS. Therefore, there was a possibility that the subject could not discriminate between the two. Adventitious contiguity of a response and a UCS might have increased response rate because of superstitious conditioning. The response-contingent reinforcer and the UCS were different in this experiment, but that did not preclude the possibility of superstitiously conditioned increases in response rate during the CS. However, once the increased response rate was established in the 120-sec CS it is not clear why rate should not have remained high during the subsequent exposure to the 40-sec CS. On the basis of these results the question of whether rate enhancement during the 120-sec CS represents adventitious reinforcement or some other phenomenon cannot be answered.

The reduced response suppression during the 40-sec CS as compared to the 12-sec CS could easily be explained as a function of the number of reinforcements that would be lost if the subject suppressed completely during the CS. Stein *et al.* (1958) showed how such an analysis could be applied to a conditioned suppression paradigm. If the same procedure is applied to the VI schedule used in this experiment, an estimated 0.61 reinforcements per session would be lost as a result of complete suppression during the six 12-sec CSs, and an estimated 2.51 reinforcements per session would be lost as a result of complete suppression during the six 40-sec CSs. However, since the suppression during the 40-sec CS was very slight or nonexistent for all subjects, the 40-sec CS duration seems to be the limit of applicability of the Stein *et al.* (1958) analysis. Their analysis could be extended to argue that response-rate increases during CS would occur if such rate increases produced an increase in reinforcement frequency. But since response-rate increases during CS did not increase reinforcement frequency in this experiment, their analysis would not provide any basis for explaining response enhancement.

An alternative explanation of the present data is provided by two-factor learning theory (*e.g.*, Mowrer, 1960; Rescorla and Solomon, 1967). Exponents of two-factor theory claim that operant and respondent conditioning are two distinctly different processes. This assertion is frequently modified by hypothesizing a relationship between the two processes in which respondent conditioning is coincidental with operant conditioning and is often considered to mediate the operant response. Rescorla and Solomon (1967) did not make an unqualified prediction about what would happen during a CS when a positive UCS was used in conjunction with a discriminably different response contingent positive reinforcer. They reported, however, that available evidence indicated that the operant response rate should increase during the CS under these conditions. The data from this experiment and from Azrin and Hake (1969) do not provide strong support for such a prediction, but the prediction was not based on any strongly held theoretical position. Two-factor theories, nevertheless, would have to incorporate these data if they were to explain the empirically observed interaction between operant and respondent conditioning when positive reinforcers and positive UCSs were used.

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