Stimulus parameters producing response summation

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Three rats learned a discrimination in which responses were reinforced on a variable interval schedule in the presence of either a light/tone combination or a no-light/no-tone combination. No responses were reinforced when the stimulus was a combination of light/no tone. These Ss responded at their highest rate when the stimulus was a no-light/tone combination. Another three Ss also learned a discrimination in which responses were reinforced during either a light/tone combination or a no-light/no-tone combination. But these Ss were never reinforced for responding when the stimulus was a combination of no light/tone. They responded at their highest rates when presented with a combination of light/no tone. The increased response rate during a stimulus that differed from the extinction stimulus along both the light and sound continua is an example of response summation. The stimulus combinations that produced response summation in this study have not previously been used to demonstrate response summation, and they support Weiss's (1969) explanation of this phenomenon.

Pavlov (1927) first described the summation of responses observed when two separately established conditioned stimuli were presented simultaneously. More recently, a number of experiments have examined the effects of the simultaneous presentation of two discriminative stimuli (S+s) on free operant response rate. In several of these experiments (Miller & Ackley, 1970; Weiss, 1964; Wolf, 1963), no responses were reinforced when the stimulus condition was the absence of light and tone (S-). A schedule of reinforcement was in effect during the presentation of either a light S+ (during which there was no auditory stimulus) or a tone S+ (during which there was no light stimulus). When light and tone were presented simultaneously, the rats in each of these experiments responded at a higher rate than they did when either S+ was presented alone. Weiss (1969) has noted these stimulus conditions as light plus no tone (L,T) or light plus tone (L,T), respectively. The same set of symbols will be used in this paper. In the same article, Weiss argued that the combinations of the on-off states of light and tone could be ordered along a "composite continuum." One end of the continuum was reached when both stimuli were off, the other end was reached when both stimuli were on. Weiss pointed out that in all the experiments described above, two of the stimuli associated with the reinforcement conditions—L,T and L,T—had elements of the extinction stimulus—L,T—as part of the compound. The stimulus that produced the highest response rate—L,T—had no elements associated with the extinction condition.

If response summation occurs when response rate in a compound stimulus with no extinction elements as compared with response rate during a compound stimulus containing extinction elements, then the specific compound stimulus producing summation need not be L,T. Thus, both Weiss (1969) and Meltzer & Freeman (1971) have shown that when L,T is the S-, and L,T and L,T are S+s, response summation occurs when L,T is presented to the S.

This experiment examined the other possible combinations of light and tone that could be used to produce response summation.

SUBJECTS

Six male hooded rats that were approximately 120 days old at the beginning of the experiment served as Ss. Each S was allowed free access to water for 15 min following an experimental session but was deprived of water at all other times. Food was continuously available in a S's home cage.

APPARATUS

The experiment was carried out in a standard Lehigh Valley experimental chamber (Model 1316) with interior dimensions of 27.32 x 30.48 x 20.32 cm. The manipulandum was a lever with an operating pressure of 20 g, located 2.86 cm above the floor and 3.80 cm from the left side of the chamber. Reinforcement was provided by a 0.06-cc liquid dipper located at the base of the front wall, midway between the sides. There were two pilot lights on the front wall of the chamber. Both lights were 5.72 cm above the floor. One light was 3.49 cm from the left side of the chamber and the other was 3.49 cm from the right side of the chamber. Light intensity

was measured 2.86 cm above the floor, 6.35 cm from the front wall, and 3.49 cm from the left side of the chamber, with the meter facing the front wall. Illumination when both pilot lights were turned on was 9.04 mL, measured with the light meter facing the front wall. The auditory stimulus was a 714-Hz tone that was 4 dB above a background noise level of 63 dB.

Electromechanical control and recording equipment was located in an adjacent room. White noise was always present in the experimental room to mask extraneous sounds.

PROCEDURE

Ss were trained to drink from the dipper in the first session of the experiment under stimulus conditions of L,T. They were allowed to earn 100 reinforcements on a continuous reinforcement schedule during the next session under the same stimulus conditions. The continuous reinforcement schedule also remained in effect during the third session, and the Ss were again allowed to obtain 100 reinforcements, but the stimulus conditions were L,T. Discrimination training began during the fourth session. There were two S+s for each of the Ss: L,T was one and L,T was the other. The S- was L,T for Ss A1, A3, and A5, and L,T for Ss A2, A4, and A6. The schedule of reinforcement during the S+ was VI 30 sec during the fourth and fifth sessions and VI 1 min for the remainder of the experiment. Each S+ presentation lasted for 2 min and was followed by an S- interval. S- lasted for a minimum of 20 sec. If the S made no response during those 20 sec, the S- ended and the next S+ was presented. If the S did respond during the S-, at least 20 sec had to pass from the time of the response before the S- ended. Sessions were terminated when each S+ had been presented 10 times. Thus, there were a total of 20 S+ presentations lasting for 40 min and a total of 19 S- presentations which lasted for some variable duration.

After 50 sessions of discrimination training, the test procedure was introduced. There were eight presentations of each S+ during the session so that the Ss' responses were reinforced on a VI 1-min schedule for a total of 32 min. There were also three test intervals during a session, and each test interval lasted for 2 min. No reinforcements were ever delivered during a test interval, and each test interval was preceded and followed by an S- presentation. There were always at least two S- presentations between any two test intervals, and the first test interval was not presented until each S+ had been presented at least

Table 1
Mean Response Rate (Responses/Minute) During Each Test Interval Stimulus*

	Position of Test Stimulus Within the Session		
	First	Second	Third
Combined Test Stimulus $\bar{L}, \bar{T}$ for A1, A3, and A5; $L, \bar{T}$ for A2, A4, and A6	46.4	42.6	39.8
$L, \bar{T}$ Test Stimulus	38.9	38.5	29.7
$\bar{L}, \bar{T}$ Test Stimulus	36.4	33.9	29.2

*The test interval mean response rate differed according to the position of the test stimulus within the session, and these differences are also shown.

once. During two of the test intervals, the stimuli were identical to the S+s: one test interval stimulus was $L, \bar{T}$ and another was $\bar{L}, \bar{T}$. The third test interval stimulus differed from S— along both the light and sound continua. Since S— was $L, \bar{T}$ for A1, A3, and A5, the stimulus presented to these Ss during the third test interval was no light plus tone ($\bar{L}, \bar{T}$). S— was $\bar{L}, \bar{T}$ for A2, A4, and A6, and the stimulus presented to these Ss during the third test interval was light plus no tone ($L, \bar{T}$). Since these stimuli are not the same for all Ss, they will simply be referred to as combined test stimuli. The order of the S+s and test intervals was changed every third day, and the testing procedure continued for 18 sessions.

We also wanted to know whether response summation could be demonstrated when responses during the combined test stimulus were reinforced. Therefore, the procedure was changed so that there were three S+s in the experiment. The two original S+s— $L, \bar{T}$ and $\bar{L}, \bar{T}$ —were retained, but the third stimulus, which differed from S— along both the light and sound continua, was also used as an S+. This stimulus will be referred to as the combined S+. Each S+ was presented for a total of 12 min during the session in six 2-min blocks. A VI 1-min schedule of reinforcement remained in effect during each of the S+s. The S+ sequence was changed every third day. There were 30 sessions during which this procedure was used.

RESULTS

Table 1 shows that the Ss had higher mean response rates during the combined test stimulus than during the other two test stimuli. All six Ss showed this effect. Table 1 also shows that the order in which the stimuli were presented affected response rate. Mean response rates were higher during the first test stimulus presentation than during the second and higher during the second than during the third. A two-factor analysis of variance showed that both the test stimulus ($F = 461.97$, $df = 2/10$, $p < .001$) and the position of the test stimulus within the session ($F =$

317.26 , $df = 2/10$, $p < .001$) significantly affected response rate.

Figure 1 shows mean response rates in blocks of six sessions for the 30 sessions in which Ss were reinforced for responding during $L, \bar{T}$ and $\bar{L}, \bar{T}$ and the combined S+. It is clear that mean response rate was highest during the combined S+ for all the Ss. The consistency of this phenomenon was much greater than during the test interval procedure. A1 responded at a higher rate during the combined S+ than during either of the other S+s in 19 of the 30 sessions. A5 responded at a higher rate during the combined S+ than during either of the other S+s in 28 of the 30 sessions. The frequency with which the other Ss showed response summation lay between these two extremes.

Although the S— response rates are not shown, five of the six Ss learned the discrimination well enough so that the mean S— response rate was never higher than the mean response rate in any of the S+s over the five blocks of sessions. However, the S— rates were still fairly high and ranged from a

mean of 7.5 responses/min for A3 over the 30 sessions to a mean of 17.3 responses/min for A5. These responses were not equally distributed over all of the S— intervals in a session, but typically occurred in prolonged bursts of responding during one or two S— presentations. Although A1 did show response summation, it did not develop a good discrimination since its response rate during S— was consistently higher than its response rate during $L, \bar{T}$ after the first block of sessions. A1 had higher response rates during both $L, \bar{T}$ and $L, \bar{T}$ than during S— prior to the introduction of the combined S+, and it is not clear why the discrimination broke down at this point.

There are two other points which should be mentioned, although they do not relate directly to response summation. First, three of the six Ss—A1, A5, and A6—had higher response rates during the $L, \bar{T}$ S+ than during the $\bar{L}, \bar{T}$ S+ throughout the experiment. Second, A6, which had a relatively stable response rate prior to the introduction of the combined S+, suddenly began to increase its response rate during all three S+s as well as during S— when the combined S+ was introduced. Both phenomena may be idiosyncratic, and there is no way of estimating their effects on response summation on the basis of this experiment.

DISCUSSION

These experiments, along with other studies that have demonstrated response summation, have shown that it does not matter which stimulus parameters are assigned to produce

Fig. 1. Mean response rates in each of the three S+s is shown above. For A1, A3, and A5, the S— was $L, \bar{T}$ and response rate was highest in the S+ that consisted of $\bar{L}, \bar{T}$. For A2, A4, and A6, the S— was $\bar{L}, \bar{T}$, and response rate was highest in the S+ that consisted of $L, \bar{T}$.

response summation. If the stimuli are restricted to one visual stimulus and one auditory stimulus, the only condition that must be met in order to produce response summation is that the S+ differ from the S- along both the light and sound continua. These data support Weiss's (1969) analysis of the response summation phenomenon.

In view of these data, it seems possible that the term "response summation" is inaccurate. The objection to this term may be understood most easily by comparing the response summation procedure to a discrimination procedure in which S+ is light and S- is no light. In that case, response rate during S+ is said to be inhibited if a previously established S- stimulus is introduced during S+ and response rate decreases. But in a response summation procedure such as the one used in this experiment, two

of the three S+s differ from S-- along only the light or tone continuum, and it follows that at least half the S- compound is always present during these S+ presentations. Therefore, response rate during the combined S+ might be considered analagous to response rate during S+ when the S is required to form a unidimensional discrimination: In neither case would any inhibitory stimulus be present. The response summation phenomenon then could be explained by the hypothesis that response rate is inhibited during either of S+s that produce response summation when presented simultaneously. Elimination of response suppression, therefore, might describe the results of combining S+s as well as does the term "response summation."

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