COMPOUNDING OF PRE-AVERSIVE STIMULI¹

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When two discriminative stimuli, each capable of maintaining a response, are combined, their compound will maintain a frequency of response greater than the frequencies maintained by the individual stimuli. This has been called additive summation. The present experiments extended the investigation of this phenomenon to a converse situation in which two pre-aversive stimuli were combined. Each pre-aversive stimulus was capable of reducing the frequency of an ongoing response. The combination of these stimuli reduced the relative frequency of response below that resulting from either stimulus. Furthermore, the compounding of two highly suppressive stimuli produced more suppression than the compounding of two less-suppressive stimuli. Evidence was also presented to suggest that the compound continued to reduce responding even when the single stimuli were no longer effective. A fourth experiment demonstrated that summation of response tendencies could not be accounted for in terms of stimulus intensity or sensory interaction.

When two discriminative stimuli (S^D s), each capable of maintaining a response, are combined, their compound produces a greater frequency of response than either stimulus alone (Wolf, 1963; Weiss, 1964). This is called additive summation of response tendencies.

The present experiments extended the generality of this compounding-summation phenomenon. In the experiments by Wolf and Weiss, the S^D s were correlated with positive reinforcement and thus maintained a higher frequency of response than in their absence. In the present experiments, stimuli having a converse effect were examined. These pre-aversive stimuli maintained a frequency of response less than the frequency emitted in their absence. Additive summation of response tendencies would predict that if two pre-aversive stimuli are combined, the frequency of response resulting from their compounding will be less than the frequency resulting from the stimuli alone.

Four experiments were conducted. The first was a test of the compound-summation phenomenon with pre-aversive stimuli. Assuming

that summation was obtained, a second experiment examined compounding under different levels of suppression. The question was whether a greater reduction would result from a compound of two highly suppressive stimuli than from a compound of two less-suppressive stimuli. The third experiment examined the persistence of summation by combining the pre-aversive stimuli while they were being extinguished. The fourth experiment examined the possibility that summation may be better accounted for in terms of stimulus intensity or sensory interaction.

EXPERIMENT 1

Subjects

Three male albino rats were maintained at 75% (275 to 300 g) of free-feeding weight during the experiment.

Apparatus

A standard Grason-Stadler operant chamber with a grid floor for the delivery of foot-shock was used. It was housed in a chest which shielded it from external stimuli.

Procedure

The subjects were first shaped to bar-press and responses produced 45-mg Noyes pellets on a continuous reinforcement schedule. After acquisition of bar pressing, the schedule was

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changed to a variable-interval 40-sec schedule (VI 40-sec). After 12 to 15 two-hour sessions, responding attained a high and steady baseline rate of at least 60 to 75 responses per minute, and a pre-aversive stimulus procedure (Estes and Skinner, 1941) was introduced. The single stimuli were a 96-db 1450-Hz tone presented through a speaker in the lower left-hand corner of the box, and the houselight, a single 6-w 120-v bulb with luminescence equal to 0.6 log foot lamberts measured at the bar. The intensity of the tone was measured with a General Radio Co. sound level meter. The frequency of the tone was measured with a Textronix Type 316 Oscilloscope. The luminescence of the houselight was measured with an SEI Exposure Photometer. The stimuli were presented separately three times each in alternating order for 4 min at 10, 30, 55, 65, 85, and 110 min in the 2-hr sessions. The order of alternation was changed every two sessions. No shock was given with the stimuli for the first four or five sessions to allow habituation to the novel stimuli. The light and tone were then combined once during each of the last two habituation sessions. Compounding occurred during one of the six stimulus periods in which only the light or tone normally appeared. There was no difference in the number of responses emitted during the single stimuli or compound presentation.

Shock was then presented at the termination of each of the six stimulus periods. The initial shock intensity and duration for each subject was 54 v for 500 msec. Shock intensity was measured from the grid floor in volts with a Heathkit Model V-7A Vacuum Tube Voltmeter. This level was increased by about 10 to 12 v and 100 msec each session until a median suppression ratio of 20 to 40% over the six periods was established. The shock intensity and duration necessary to produce this level of suppression was 84 v, 800 msec for S1; 69 v, 600 msec for S2; and 89 v, 800 msec for S3. The suppression ratio, an index of the amount of response reduction produced by the pre-aversive stimuli, was computed by taking the difference between the number of responses emitted during the 4 min before onset of each stimulus (A) and the number emitted during the 4 min the stimuli were present (B), and dividing by A; *i.e.*, $A - B/A$. The result is a per cent suppression measure. Food reinforcement was independent of the tone, light, and

shock and was scheduled according to VI 40-sec throughout the session. Reinforcements not collected during the pre-aversive stimuli remained available after the pre-aversive stimuli terminated.

A steady baseline level of suppression was attained for each subject after 10 to 14 sessions. The light and tone were then presented together for 4 min during the periods in which only the light or tone normally appeared, except for the first period. Tests with the compound were never terminated with shock. The individual stimuli continued to be paired with shock. The period in which the compound appeared changed each session and alternated between periods normally occupied by the light or tone. For S1, one compound test was performed over each of 10 sessions, and S3 was tested for nine sessions, one test each session. For S2, two compound tests were performed during each session, except during Sessions 4, 6, 7, and 10 when only one test was performed, for a total of 16 tests over 10 sessions.

RESULTS

The suppression ratios, expressed in terms of per cent suppression, for each subject under each stimulus condition are presented in Fig. 1. The suppression ratios for the compound are plotted against the highest and median ratios of all the presentations of the individual stimulus elements in a given session.

The results clearly indicate that the compounding of individual stimuli reduced the relative frequency of responding to a greater degree than did the individual stimuli. Suppression ratios were used to control for any within-session variability in responding. However, the smaller the size of the suppression ratio, the greater the relative frequency of responding; likewise, the greater the size of the suppression ratio, the less the relative frequency of responding.

EXPERIMENT 2

Procedure

Two different subjects, S4 and S5, were used in a procedure similar to that of the first experiment. An initial median suppression ratio of 10 to 25% was established. The final

Fig. 1. Suppression ratios maintained by the individual stimulus elements and their compound for each session. H = highest and M = median suppression ratio.

shock intensities and durations were 66 v, 700 msec for S4 and 54v, 500 msec for S5. Nine compound tests, one test each session, were then conducted. After these tests were completed, the shock level was increased over sessions until a median suppression ratio of 50 to 60% was obtained for both subjects. The shock levels were 94 v, 900 msec for S4 and 66 v, 600 msec for S5. Nine more compound tests were then conducted.

RESULTS

The results are presented in Fig. 2. They indicate that the greater the suppression maintained by the single stimuli, the greater the suppression maintained by their compound.

Cumulative records of typical performance from Exp. 1 and 2 are presented in Fig. 3. Note that despite the marked reduction in responding produced by the compound, subjects still usually collected almost all of the available reinforcements, just as they collected nearly all reinforcements under the lower levels of suppression. This result is consistent with results reported by Stein, Sidman, and Brady (1958). They varied the duration and the rate of presentation of the pre-aversive stimuli and found that the number of reinforcements under each condition was relatively constant despite wide differences in suppression produced by the two conditions. They suggested that the subject's responses were distributed in such a way as to minimize losing reinforcements. The present results support this finding.

During the first period for S3, Session 3, no suppression was obtained. This lack of suppression during the first presentation of the light or tone occasionally occurred, and for this reason no compound tests were ever performed then. The subjects were first allowed to warm-up by experiencing shock at least once.

Fig. 2. Suppression ratios maintained by the elements and their compound under low (A) and high (B) levels of suppression.

Fig. 3. Cumulative records of S3, third session of Exp. 1; S4, fourth session under low suppression, Exp. 2; and S4, third session with high suppression, Exp. 2. Each record is a complete session. L=light, T=tone, C=compound. The number of responses emitted before (P) and during (D) the pre-aversive stimulus, as well as the resulting suppression ratio for each of the six stimulus periods, is given. The depressions in the baseline at the bottom of the figure indicate the 4-min pre-aversive stimulus periods. The slash marks in the records denote the delivery of food reinforcement.

For S3 and S4, Session 4, the lowest suppression ratio, except for the first period for S3, occurred during the period immediately following the compound test. This drop in suppression occasionally occurred and may have been a result of not presenting shock with the preceding compound test period. Otherwise, for the majority of sessions, the level of suppression remained quite consistent, as illustrated by the record of S4, Session 4. Furthermore, examination of the performance of S2 in Fig. 1 reveals that the level of suppression attained in the second compound test in a single session was not attenuated by the preceding test.

EXPERIMENT 3

The persistence of the compound effect was examined by discontinuing shock after the second series of tests with S4 and S5. Otherwise, the procedure remained unchanged. One compounding test was conducted each session

until it was apparent that there was no longer any difference in suppression produced by the individual stimuli and compound.

RESULTS

The data are presented in Fig. 4. The immediate effect of discontinuing shock was a permanent reduction of the median suppression ratios to near-zero or negative values. However, the highest ratio for each session was usually above zero. In contrast to the median ratio, the compound suppressed responding much longer.

DISCUSSION

Taken together, the results of the first two experiments are wholly consistent with a summation-of-response tendencies interpretation. The compound produced a relative frequency of response less than that resulting from the single stimuli. Furthermore, the compounding

Fig. 4. Suppression ratios maintained by the elements and their compound after shock was discontinued.

of two highly suppressive stimuli produced more suppression than the compounding of two less-suppressive stimuli.

In the third experiment, compounding still produced suppression even though the individual stimuli no longer appeared to be aversive. During some of the sessions, the ratio for the single stimuli was substantially above zero, and, therefore, the single stimuli may still have had aversive features, even though the median ratios were zero. During other sessions, the highest ratio was at zero and the compound still produced a marked level of suppression. Weiss (1964) reported a similar effect. He found that even when responding was extinguished in the presence of the component stimuli, their compound nevertheless evoked responding. Weiss hypothesized that each separate stimulus might be below response evocation threshold, but that their compound raised responding above threshold.

Strictly speaking, the term "additive summation" or even "summation" is somewhat of a misnomer. These terms imply that the level of responding produced by the compound is a simple sum of the response levels produced by the individual components. However, both Wolf (1963) and Weiss (1964) found that the frequency of response to the compound was greater than the sum of the individual frequencies. In other instances (Kimble, 1961, p. 87), the response to the compound is less than the sum of the individual responses. In the present Exp. 1, the level of suppression maintained by the compound exceeded a combination of the median suppression levels of the individual stimuli. Furthermore, in Weiss' (1964) study and the present Exp. 3, the compound was still able to pro-

duce an effect even when the single stimuli no longer could do so. Such evidence suggests that the response tendencies maintained by the single stimuli do not combine in a simple additive fashion. A multiplicative relationship would probably be more appropriate. Or, that the compound is not a simple sum of the single frequencies may mean that the scale of measurement lacks the necessary equally spaced intervals for measuring a possible underlying lawful or regular relationship. For example, the A-B/A ratio used in the present experiments is but one of at least five possible ways of computing the degree of suppression (Lyon, 1968). Since all these measures are arbitrary, it is perhaps not surprising that they do not yield a precise and orderly quantitative relationship.

The interpretation of results stressed here has been in terms of summation of decrements in the frequency of response as produced by conditioned suppression. If, however, the behavioral effect produced by this procedure is defined in more subjective terms as an emotional state (*i.e.*, conditioned "fear", conditioned "anxiety", conditioned "emotional response"), then the fear or anxiety to the compound could be interpreted as a summation of the fear to the individual fear-producing stimuli.

Of more immediate importance, however, is whether it is necessary to interpret the results in terms of summation. An alternative interpretation is that the results may be accounted for in terms of stimulus intensity or sensory interaction. With regard to stimulus intensity, Kessen (1953) found that the number, speed, and probability of occurrence of wheel turns to avoid shock all increased with increasing intensity of a light. Kieffer (1965) demonstrated that rats responded at a higher rate on an FI 2-min schedule with a correlated buzzer than on the same schedule without the buzzer. Kamin and Brimer (1963) reported highly significant effects of intensity of pre-aversive stimuli. With shock intensity and duration held constant, the more intense the pre-aversive stimuli the greater the level of suppression.

A demonstration of sensory interaction first involves training subjects to respond differentially to different intensities of a stimulus. After discriminative control has been established, sensory interaction is demonstrated

when a stimulus from another sensory modality (accessory stimulus), presented simultaneously with the S^D from the first modality, produces the same effect as increasing the intensity of the S^D (Carter, Salive, and Zajonc, 1966). Carter *et al*, trained pigeons to peck at two keys, each in the presence of a different intensity tone. Even though the test tones were of the same intensity as the training tones, the presentation of an accessory light simultaneously with the tone changed the probability of the correct key choice in the same manner as increasing the intensity of the tone.

Wolf (1963) and Weiss (1964) and the present study all used a light and tone as stimuli. The differences in frequency produced by their compound may have been due to sensory interaction, rather than summation of response tendencies. Wolf also used two sets of three lights as S^D s. The higher frequency of response maintained by the compound of six lights may have been due to stimulus intensity rather than to summation. In order to determine whether a summation or sensory interaction-stimulus intensity interpretation would better account for the data, a fourth experiment was conducted. Only one stimulus was established as a pre-aversive stimulus. When this stimulus was so established, it was then compounded with a second stimulus. If the compound produced a greater level of suppression than the single pre-aversive stimulus, a sensory interaction-stimulus intensity interpretation would be favored. However, if the addition of the accessory stimulus had no effect upon the level of suppression, a summation interpretation would be favored.

EXPERIMENT 4

Procedure

Two rats, S6 and S7, were placed under a procedure identical to that used in the first two experiments, except that only the light was presented during each of the six stimulus periods. The shock was adjusted until the light maintained a median 10 to 30% baseline suppression level. The final shock levels were 135 v, 1000 msec for S6 and 111 v, 1000 msec for S7. The equipment that controlled shock duration did not allow for durations exceeding 1000 msec. When this limit was reached, intensity was increased until the de-

sired suppression level was attained. The light was then compounded with the tone, once each session for seven sessions. Shock was correlated only with termination of the light.

In order better to compare the results of this procedure with those of the first two experiments, the tone was also established as a pre-aversive stimulus after the seventh test. The light and tone were alternated over the six stimulus periods in a procedure identical to that of the first two experiments. Since S6 had suppressed almost completely to the light by the seventh test, the shock was reduced to 120 v, 1000 msec in order to reestablish the median 10 to 30% baseline level of suppression. With the introduction of the tone for S7, suppression was reduced. Shock was increased to 123 v, 1000 msec in order to reestablish the baseline. The light and tone were then compounded, once each session for seven sessions. Shock occurred only with the termination of the individual stimuli.

RESULTS

The results are presented in Fig. 5. When only the light was established as a pre-aversive stimulus, the addition of the tone had no appreciable effect upon suppression. However, when the tone was also established as a pre-aversive stimulus, the compound consistently exceeded the highest value of either component.

DISCUSSION

The compound produced a greater level of suppression than did either component only when each stimulus was individually established as a pre-aversive stimulus. These results suggest that a summation of response tendencies interpretation better accounts for the data. The majority of sensory interaction experiments have been concerned with the effect of accessory stimuli on sensory thresholds (London, 1954; Carter, 1962). The only cases of sensory interaction which have investigated the effect of accessory stimuli on patterns of behavior appear to be of the type reported by Carter *et al* (1966); that is, the effect of accessory stimuli on discrimination performance. In this type of study, the measure of behavior is which of two alternatives is selected. Frequency of responding or changes in frequency

Fig. 5. A: Suppression ratios maintained by the light alone and by the light and tone. The tone was not a pre-aversive stimulus. B: Suppression ratios maintained by the compound and its components. The values for the components are the highest ratios in that session. Both stimuli were pre-aversive stimuli.

are not relevant. Accessory stimuli shift the choice distribution in the direction of the more-intense stimulus. Whether an accessory stimulus will also increase or decrease the frequency of a response in a manner similar to increasing the intensity of a stimulus within a single modality seems doubtful in light of the results of Exp. 4. These data and the studies of Kessen (1953), Kieffer (1965), and Kamin and Brimer (1963) suggest that changes in stimulus intensity within a single modality will effect changes in response frequency which intermodality sensory interaction will

not do. The results obtained by Wolf (1963), Weiss (1964), and the present results appear to be interpretable in terms of summation of response tendencies.

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