COMPOUNDING OF DISCRIMINATIVE STIMULI CORRELATED WITH CHAINED AND MULTIPLE SCHEDULES¹

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In studies of stimulus compounding (1) the stimuli are presented randomly, (2) primary reinforcement is correlated with each stimulus, (3) a specific response is emitted during each stimulus, and (4) the response is necessary to produce the reinforcer. The present experiments assessed the importance of these procedures by (1) presenting light and tone stimuli in fixed order, (2) removing reinforcement (food) during one stimulus, (3) preventing the response (lever pressing) from being emitted, and (4) eliminating the contingency between lever pressing and food. These variables were presented in various combinations within the context of chained and multiple schedules. When the stimuli were combined in the schedule component correlated with each stimulus, the frequency of lever pressing increased in most instances (additive summation). This suggests that the effect of combining stimuli was not closely tied to the specific procedures used in previous experiments. However, presenting the stimuli in a fixed order did have an effect: the level of responding to the compound was generally greatest when the stimuli were combined in the component correlated with the higher frequency of lever pressing to the single stimulus. Additive summation failed to occur consistently when response-independent food was correlated with each stimulus, and when both lever pressing and food were eliminated during one stimulus.

In many studies of stimulus compounding, separate discriminative stimuli are correlated with schedules of food reinforcement. When the stimuli are combined, the rate of responding is different than that to either single stimulus. For example, additive summation is said to occur when the rate to the compound exceeds that to each stimulus (Weiss, 1964; Wolf, 1963). These results have been derived from a standard set of procedures: (1) The stimuli were presented randomly, so that the stimulus that occurred next was not predictable. (2) A primary reinforcer (food) was presented during each stimulus. (3) A specific response (e.g., lever pressing) was emitted during each stimulus. (4) Presentation of the reinforcer was dependent on these responses. Concerning the first point, the stimuli could be presented in a fixed, alternating order so that the next stimulus could be anticipated. Such ordering could affect behavior during compounding, since stimuli would be combined in a context in

which one stimulus and its correlated schedule of reinforcement would normally occur. The control of performance by discrimination of the sequence of presentation of stimuli was demonstrated by Boren and Navarro (1959) and Ferster and Skinner (1957). Their subjects had a schedule in which two stimuli alternated with each other. A fixed-interval schedule was correlated with one stimulus and a fixed-ratio schedule with the other. Boren and Navarro found that when two consecutive intervals were arranged, subjects continued to alternate interval and ratio behavior. Ferster and Skinner's subjects continued to alternate interval and ratio behavior even after the stimuli were removed. Concerning the other three points, removing the reinforcer during one stimulus, eliminating the contingency between the response and the reinforcer, or preventing the response from being emitted during one stimulus could likewise affect the pattern of responding during compounding.

The present experiments assessed the importance of these procedures by presenting them in various combinations. These are shown in Table 1. The two stimuli were always presented in a fixed, alternating order. Food was eliminated during one stimulus (col-

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Table 1
Summary of the Conditions Presented to Each Group of Subjects

Row	Subjects	STIMULUS 1			STIMULUS 2		
		<i>Is Food Presented?</i>	<i>Can Lever Pressing Occur?</i>	<i>Is Lever Pressing Necessary?</i>	<i>Is Food Presented?</i>	<i>Can Lever Pressing Occur?</i>	<i>Is Lever Pressing Necessary?</i>
	Column 2	3	4	5	6	7	8
1	1-11	Yes	Yes	Yes	Yes	Yes	Yes
2	1-11	No	Yes	Yes	Yes	Yes	Yes
3	12-17	Yes	Yes	No	Yes	Yes	Yes
4	18-22	No	Yes	Yes	Yes	Yes	No
5	23-27	Yes	Yes	No	Yes	Yes	No
6	28-35	Yes	No	No	Yes	Yes	Yes
7	36-38	No	Yes	Yes	Yes	No	No
8	39-42	No	No	No	Yes	Yes	Yes

umn 3) in rows 2, 4, 7, and 8. The contingency between lever pressing and food (or between lever pressing and termination of the stimulus when the stimulus was not correlated with food) (columns 5 and 8) was eliminated in rows 3 through 8. Lever pressing was not permitted to occur (columns 4 and 7), by retracting the lever during one stimulus, in rows 6, 7, and 8.

METHOD

Subjects

Forty two experimentally naive male Holtzman albino rats, 150 to 250 days old, were maintained at 85% of their free-feeding weights (about 450 to 550 g).

Apparatus

Standard single- and double-lever Grason Stadler rat chambers were equipped with retractable levers. A tone and a light served as the stimuli. The speaker was 6.7 cm above the translucent roof, 10.5 cm from the right side wall, and 17.8 cm from each lever. The tone had a frequency of 1500 Hz (0.0002 dynes/cm²) and an amplitude 8 dB above the 74-dB ambient noise level. The light was directly underneath the speaker and its intensity was 61.6 cd/m² (18.0 ft candles). A houselight of 5.8 cd/m² (1.7 ft candles) was located by the front upper left-hand corner of each box and always remained on. Measurements were made at the levers. The food cup in the single-lever box was located just beneath the lever on the same wall. The food cup in the two-lever box was located midway and just beneath each lever on the same wall. A force of 25 g (2.5 N) was required to depress each lever. The reinforcer

was a single 45-mg Noyes pellet delivered when the appropriate schedule had been completed.

Procedure

The light and tone were always presented in alternating order for all subjects. Whether the light or tone appeared first or second was counterbalanced across subjects. A period of extinction occurred between presentations of the two stimuli. During extinction, neither the light nor the tone appeared and food was never presented. A separate lever was correlated with each stimulus for Subjects 1 through 6 and 12 through 27. The left lever was correlated with the first stimulus and the right lever with the second. Only one lever appeared at a time. For Subjects 7 through 11, one lever was correlated with both stimuli and was always extended. For Subjects 28 through 42, a single lever was used, and it was retracted during one stimulus and extended during the other.

After lever pressing was shaped, subjects were exposed to chained or multiple schedules. Within the context of these schedules, three conditions were presented: (1) Lever pressing was necessary to terminate each stimulus. In the multiple schedule, food was also presented when each stimulus terminated. However, in the chained schedule, food was presented when the second stimulus terminated, but not when the first stimulus terminated. (2) Food was presented independently of lever pressing. (3) Lever pressing was prevented from occurring during one stimulus.

In the first condition, Subjects 1 through 11 were exposed first to the chained schedule and

then to the multiple schedule. Initially, with the chained schedule, the first response emitted after 3 sec (a fixed-interval or FI 3-sec schedule) terminated the first stimulus, retracted the left lever and extended the right lever in the two-lever box, and produced a period of extinction. Each response prolonged extinction for 1 sec. If there were no responses, the extinction period varied from 5 to 15 sec, with a mean of 10 sec. When extinction terminated, the second stimulus appeared and food was provided according to an FI 3-sec schedule. Upon delivery of food the stimulus was terminated, the right lever was retracted and the left lever extended in the two-lever box, the extinction period was re-instated, and the sequence was then repeated. When lever pressing was maintained by both stimuli and had ceased during extinction, the duration of the FI was increased in increments of 2 sec. Over a nine- to 14-day period, the duration of the FI was increased to 20 sec. The mean duration of the extinction period was increased to 15 sec; each response prolonged it for 2 sec and then for 5 sec. This final schedule with four components, *chain* EXT 15-sec FI 20-sec EXT 15-sec FI 20-sec, continued for 30 days.

Tests of stimulus compounding then occurred. The light and tone were combined eight times during each of two sessions, for a total of 16 tests. During each test session, the stimuli were combined four times in each of the two components where only the light or tone would have normally occurred. The tests alternated between components and occurred on the average of every seventh appearance of a stimulus. The light and tone were presented separately in their respective components during all other components. Food continued to be presented only in the component correlated with the second stimulus. The subjects were then exposed to *mult* EXT 15-sec FI 20-sec EXT 15-sec FI 20-sec for 30 days. The stimuli were then combined 16 times during two test sessions in exactly the same way as with the chained schedule.

In the second condition (response-independent food), Subjects 18 through 22 were exposed to chained schedules in which the second stimulus was terminated and food was presented independently of lever pressing (a fixed-time or FT schedule). A lever press was required to terminate the first stimulus. The final schedule, *chain* EXT 15-sec FI 20-sec

EXT 15-sec FT 20-sec, was approached in small increments and continued for 30 days. The stimuli were then combined 16 times during two test sessions, in exactly the same way as with the previous chained schedule. Subjects 12 through 17 and 23 through 27 were exposed to *mult* EXT 15-sec FI 20-sec EXT 15-sec FI 20-sec until lever pressing was maintained and the ratio of responses during extinction to those during the stimulus was less than 1:10. The first stimulus was then terminated and food was provided independently of lever pressing for Subjects 12 through 17 (*mult* EXT 15-sec FT 20-sec EXT 15-sec FI 20-sec). Both stimuli were terminated and food was provided independently of lever pressing for Subjects 23 through 27 (*mult* EXT 15-sec FT 20-sec EXT 15-sec FT 20-sec). These schedules continued for 30 days. The stimuli were then combined 16 times during two test sessions, in exactly the same way as with the previous multiple schedule.

In the third condition (lever retracted during one stimulus), the final schedule for Subjects 36 through 38 was *chain* EXT 15-sec FI 20-sec EXT 15-sec FT 20-sec. This schedule was approached in small increments. The lever was retracted when the FI component terminated. Food was presented and the second stimulus was terminated 20 sec after its appearance, the lever was extended, and the sequence was repeated. For Subjects 39 through 42, the final schedule was *chain* EXT 15-sec FT 20-sec EXT 15-sec FI 20-sec. Subjects were placed directly on this schedule, since there was no concern with having to maintain responding during the first stimulus. The lever was retracted during the first stimulus. After 20 sec, this stimulus was terminated and the lever was extended. Food was provided according to an FI 20-sec schedule during the second stimulus, the lever was retracted, and the sequence was repeated. Subjects 28 through 35 were presented with a multiple schedule in which the lever was retracted during one stimulus. When the lever was retracted, food was presented after 20 sec, the stimulus was terminated, and the lever was extended. Food was provided according to an FI 20-sec schedule during the other stimulus. These schedules continued for 25 to 30 days. The stimuli were then combined eight times in one test session, during the component in which the lever was extended.

RESULTS

The data for the chained and multiple schedules are presented in terms of when (1) a lever press was necessary to terminate each component stimulus (Figure 1); (2) food was presented independently of lever pressing (Figure 2); (3) the lever was retracted during one stimulus (Figure 3). Where the lever was retracted, the data are presented in terms of the frequency of lever pressing to the single and compound stimuli that occurred in the component in which the lever was extended. The data for the other animals are presented in

terms of the frequency of lever pressing in each component to the single and compound stimuli correlated with that component. With two exceptions, the frequency correlated with the single stimulus of one component was either greater or less than that correlated with the single stimulus of the other component. The frequency of lever pressing to the compound is presented according to whether the stimuli were combined in the component correlated with the higher or lower frequency of lever pressing to the single stimulus. Each mean is based on the total number of lever presses during all presentations of the single

Fig. 1. Mean frequency of lever pressing for each animal to the single and compound stimuli when a response was required to produce food and/or terminate the component stimulus. The data for responding to the single stimuli are presented in terms of whether the frequency of lever pressing to the stimulus of one component was lower (△) or higher (○) than that to the stimulus of the other component. The data for responding to the compound are presented in terms of the frequency of lever pressing to the compound in the component correlated with the lower (▲) and higher (●) frequency to the single stimulus. Subject 4 died before completing training with the multiple schedule. Separate levers were used with Subjects 1 through 6, and the same single lever was used with Subjects 7 through 11.

and compound stimuli during all test sessions. The means for the single stimuli were representative of the means obtained during training. The effect of the compound did not vary over tests, except for Subjects 36 through 38, where the frequency of lever pressing declined with successive presentations.

In Figure 1, when the stimuli were combined in the component correlated with the higher frequency of lever pressing to the single stimulus, responding was greater than to the single stimulus of the same component in 10 of 11 and 10 of 10 instances with the chained

and multiple schedules, respectively. When the stimuli were combined in the component correlated with the lower frequency of lever pressing, responding was greater than to the single stimulus of the same component in nine of 11 and 10 of 10 instances with the chained and multiple schedules, respectively. Also, the level of responding to the compound was greater when the stimuli were combined in the component correlated with the higher frequency of lever pressing, compared to when the same stimuli were combined in the component correlated with the lower frequency

Fig. 2. Mean frequency of lever pressing for each animal to the single and compound stimuli when response-independent food was presented during the first stimulus (left and middle panels) and during both stimuli (right panel). See Figure 1 for an explanation of how the data are presented.

of lever pressing. This occurred in 11 of 11 and eight of 10 instances with the chained and multiple schedules, respectively.

In Figure 2, when the stimuli were combined in the component correlated with the higher frequency of lever pressing, responding was greater than to the single stimulus of the same component in six of six, five of five, and three of three instances with the multiple schedule of the left panel, the chained schedule, and the multiple schedule of the right panel, respectively. For this last schedule, the frequency of lever pressing to each single stimulus was identical for Subjects 25 and 27. For Subject 25, the frequency of lever pressing during compounding in each component was identical and exceeded that to the single stim-

uli. For Subject 27, the frequency of lever pressing during compounding in each component was the same as the frequency of lever pressing to the single stimuli (zero responses). When the stimuli were combined in the component correlated with the lower frequency of lever pressing, the frequency of lever pressing was greater than to the single stimulus of the same component in six of six, five of five, and one of three instances with the multiple schedule of the left panel, the chained schedule, and the multiple schedule of the right panel, respectively. The level of responding to the compound was greatest when the stimuli were combined in the component correlated with the higher frequency of responding to the single stimulus in six of six, three of five, and

Fig. 3. Mean frequency of lever pressing for each animal to the single and compound stimuli when the lever was retracted during one stimulus (left panel), the second stimulus (middle panel), and the first stimulus (right panel).

two of three instances with the multiple schedule of the left panel, the chained schedule, and the multiple schedule of the right panel, respectively.

When the lever was retracted during one stimulus (Figure 3), the frequency of lever pressing to the compound exceeded that to the single stimulus of the same component in six of eight, three of three, and zero of four instances with the multiple schedule, the chained schedule of the middle panel, and the chained schedule of the right panel, respectively.

DISCUSSION

Except for the data illustrated in the right panels of Figures 2 and 3, increased responding consistently occurred during compounding in each component: the frequency of lever pressing to the compound exceeded that to the corresponding single stimulus in 70 of 75 possible instances. This suggests that the effect of compounding was not closely tied to the specific procedures used in previous compounding experiments. However, the magnitude of this increase was not identical for each group. The median per cent change in responding during compounding relative to the level of responding to the corresponding single stimulus was found for each group. Lever pressing could occur in only one component for those animals with the lever retracted in the other component. Medians were therefore computed for the other groups only with the data obtained when compounding occurred in the component correlated with the higher frequency of lever pressing to the single stimulus. When a response was required to terminate each stimulus, the median increase for the chained and multiple schedules taken together was 40%. When response-independent food occurred in one component, the increase was 33%. When lever pressing was prevented in one component, the increase was 23%. This last situation can be considered to represent the combining of stimuli correlated with responses of different topography (lever pressing and behavior other than lever pressing). Miller and Price (1974) combined stimuli that maintained lever pressing and running. The frequency of lever pressing increased, but the magnitude of this increase was not as great as when each stimulus maintained lever pressing.

Although additive summation did occur during compounding, it is also apparent that presentation of the stimuli in a predictable, alternating order did affect the frequency of lever pressing in each component during compounding. This was particularly evident with the chained schedule, where a response was required to terminate each stimulus (left panel of Figure 1), and the multiple schedule with response-independent food during one stimulus (left panel of Figure 2). A much lower frequency of lever pressing was generally maintained by the stimulus not correlated with food in the chained schedule and by the stimulus correlated with response-independent food in the multiple schedule. In all instances, the level of lever pressing to the compound was greatest when the stimuli were combined in the other component. Since the subjects responded quite differently to the same physical compound, the component and its correlated level of responding to the single stimulus were discriminated and did control the pattern of responding during compounding. Thus, the compound can be considered to be composed of three elements: Light + Tone + Light- or Tone-Correlated Component. This pattern of responding also occurred, but less frequently, with the multiple schedule when a response was required to terminate each stimulus (right panel of Figure 1), and with the chained schedule with response-independent food during the second stimulus (middle panel of Figure 2). In these schedules, the stimuli maintained more similar levels of responding, in that the ratio between the higher and lower frequencies was generally more similar than with the other chained and multiple schedules. The level of responding to each compound would be expected to be more similar and not to show as high a relationship with the level of responding to the single stimulus of the same component.

These results were obtained when the same or separate levers were used, although the effect of the compound was relatively smaller with the separate levers. This suggests that the subjects were able to discriminate the component that was present in either situation. When separate levers were used, similar results were obtained when the compound was formed by superimposing light upon tone in the presence of the tone-correlated lever, and *vice versa*. Miller (1973) also used separate

levers and found that superimposing light upon tone or tone upon light similarly or differently affected the pattern of responding, depending upon the particular procedures that were used. The particular procedures used in the present study also probably accounted for the similarity of effects. For example, both the light and tone and their levers appeared frequently during the same session. In Miller (1973), superimposing each stimulus upon the other affected responding differently when only one stimulus and its lever appeared during a session.

Additive summation failed to occur consistently with the multiple schedule with response-independent food during each stimulus (right panel of Figure 2). Responding was reduced during compounding with the chained schedule with the lever removed during the first stimulus (right panel of Figure 3). These two schedules were uniquely different from the schedules in which additive summation was consistently found. In these latter schedules, both food and lever pressing occurred and at least one of these events occurred during each stimulus. However, in the multiple schedule with response-independent food during each stimulus, several animals essentially did not lever press during the single stimuli. In the chained schedule, neither food nor lever pressing occurred during one stimulus. The other interesting situation in which lever pressing occurred but food was not provided during both stimuli was approximated by Weiss and Levine (1973). Rats were exposed to a chained schedule in which the first stimulus was either a light or tone presented separately. Additive summation did not occur when the stimuli were combined.

With the multiple schedule of the present study, it seems reasonable that if the subjects did not lever press at all during presentations of the single stimuli, they would also not lever press when the stimuli were combined. Miller and Ackley (1970) showed that the frequency

of lever pressing to the compound was directly related to the frequency of lever pressing to the single stimuli. The reasons for the results obtained with the chained schedules of the present study and of Weiss and Levine (1973) are not as clear. Weiss and Levine suggested that the rates of reinforcement and responding in each component be viewed within the context of the rates of reinforcement and responding conditioned to the other stimuli of the schedule. In the chained schedule of the present study, the rates of reinforcement and lever pressing during the first stimulus were both zero, but were substantially above zero during the other stimulus.

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