*COMPOUND STIMULUS CONTROL BY DISCRIMINATIVE
STIMULI ASSOCIATED WITH HIGH AND
MODERATE RESPONSE RATES¹*

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Four rats received water on a fixed-ratio schedule for lever pressing in the presence of a tone (or light) stimulus and on a variable-interval schedule in the presence of a light (or tone) stimulus. Following stabilization of a high response rate during the fixed-ratio component and a moderate response rate during the variable-interval component, brief periods with the light and tone presented simultaneously but with no responses reinforced were inserted into the regular training schedule. Response rates during the compound stimuli were intermediate between the response rates controlled by the individual fixed-ratio and variable-interval associated stimuli.

Stimulus compounding represents the simultaneous presentation of two or more stimuli that have each separately maintained discriminative control of responding. Additive summation occurs when a higher response rate is produced by the compounded stimuli than by any singly presented component stimulus. Response averaging results when the response rate to the compounded stimuli is intermediate between rates controlled by individual stimuli.

Additive summation has resulted when the individual discriminative stimuli are both associated with either variable-interval (Wolf, 1963; Weiss, 1964) or fixed-interval (Miller and Ackley, 1970) reinforcement schedules controlling moderate and similar response rates. Interval schedules assign reinforcement for the first response that occurs following a designated interreinforcement interval; with a fixed-interval (FI) schedule the interreinforcement interval is constant, and with a variable-interval (VI) schedule the interreinforcement intervals vary randomly about a specified mean interval.

Response averaging has been found when one discriminative stimulus controls a moderate response rate and the other stimulus occasions a very low response rate via either extinction (Cornell and Strub, 1965) or the selective reinforcement of long interresponse

times (Weiss, 1967). Variable-interval schedules of reinforcement were used by both Cornell and Strub (VI 1-min) and Weiss (VI 0.5-min in order to control moderate response rates.

Weiss (1967) proposed that a relatively large difference between the response rates associated with individual discriminative stimuli (such as the 18 to 1 ratio he reported) is sufficient to produce averaging. If this is true generally, response averaging should result to compounded stimuli that individually control widely differing response rates along any portion of the response rate continuum. The present study investigated the generality of Weiss' response-rate-differential hypothesis by compounding stimuli that were individually associated with a fixed-ratio 25 and a variable-interval 1-min schedule and thereby controlled a high and a moderate response rate respectively. On a fixed-ratio (FR) 25 schedule, the reinforcer is produced by every twenty-fifth response.

METHOD

Subjects

Four naive female albino rats of the Holtzman strain and approximately 110 days old served. They were given free access to Purina chow except during the experimental session but were restricted to a 10-min water access period each day beginning one week before the experiment and continuing throughout the experiment.

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Apparatus

The subjects were run in a standard Lehigh Valley operant chamber with sound attenuating shell (model 1316) equipped to dispense 0.04-cc water reinforcers. During the experiment only the right-hand lever was present. Continuous white masking noise was produced by a Grason-Stadler model 455C Noise Generator and was adjusted to raise the ambient noise level in the chamber to 58 db, as measured over the lever with a General Radio Company model 1551-C sound level meter (scale C). The two discriminative stimuli used were the chamber's houselight, which was energized with 18 v/ac by a variable transformer, and a 1500 Hz tone produced by a Hewlett-Packard Audio Oscillator model 200 AB. The tone was scheduled to broadcast intermittently, having a cyclic 0.8-sec on period and a 0.2-sec off period each second. During its on period, it raised the sound level in the chamber from the constant white noise level of 58 db to 75 db, measured directly over the lever.

The operant chamber was situated in a 10 by 5 by 8 ft (3.6 by 1.8 by 2.6 m) room constructed of cinder block, and the electro-mechanical scheduling equipment, response counters, and cumulative recorders were located in an adjoining room.

Procedure

Following preliminary magazine training and lever-press shaping, the subjects were placed on the following multiple chain schedule. During each S_2 component, a 7-sec no-response requirement schedule (DRO 7-sec) was in force which when met produced on a 50% random sequence either the VI 1-min or the FR 25 S_1 component. Lever presses during the DRO component reset the 7-sec interval. During the VI 1-min component, responses were reinforced according to a randomized sequence of 12 intervals ranging from 2.6 to 209 sec obtained from Fleshler and Hoffman's (1962) progression. Each S_1 component remained in force for five reinforcements, after which the S_2 component was reinstated. Thus, throughout daily 1-hr sessions, a five-reinforcement VI 1-min component was randomly alternated with a five-reinforcement FR 25 component with a DRO 7-sec component separating each successive component.

The DRO 7-sec component was used to insure that both S_1 component stimuli would gain individual discriminative control over responses in their respective components and obviate the possibility that the presence *versus* absence of one stimulus would alone assume full discriminative control.

For animals S-1 and S-3, the houselight was correlated with the variable-interval component and the tone was correlated with the fixed-ratio component. For S-2 and S-4 the stimuli and their correlated reinforcement schedules were reversed; the light was present during ratio components and the tone was present during interval components. During the DRO 7-sec component the chamber was dark and only the white noise was present. Training on the multiple chain schedule was continued for each subject until at the end of a 2.5-month period, characteristic and stable responding to the fixed-ratio and variable-interval schedules was obtained and responding during DRO components was negligible (usually zero).

Compound stimulus testing was carried out for two consecutive sessions following stabilization on the training schedule. During each test session, four 1-min non-reinforcement compound stimulus probes (both light and tone present) were inserted into the regular schedule. For each subject, four probes were directly preceded by a variable-interval component and four by a fixed-ratio component over the two test sessions. The sequence of directly preceding schedule components was counter-balanced across the four subjects. Each test probe was immediately preceded and followed by a DRO component. Responses made during each 1-min probe were recorded on counters, and the ongoing response rates during the S_1 components directly preceding the test probes were obtained from the cumulative record using a response-rate template (Carman, 1968).

RESULTS

Stabilized performance on the multiple chain schedule revealed that the individual discriminative stimuli maintained clearly differentiated control over the response rates for each subject. Responding ceased abruptly with the onset of the DRO component, and at the onset of the discriminative stimulus

for either S_1 component responding immediately resumed at a rate characteristic of the correlated reinforcement schedule. Responding during the variable-interval schedule never achieved the steadiness typically found with other rats in our laboratory during simple VI schedules. Rather, the performance was often composed of sequences of small bursts of three or four responses that alternated with short pauses. The response-bursting pattern may have been due to transfer of the high rates established and maintained during the interacting fixed-ratio components, and it appeared to be a stable characteristic throughout the training phase.

Figure 1 presents the response rate in each of the eight 1-min compound stimulus tests for each animal together with the response rate during the directly preceding reinforcement component. The preceding fixed-ratio run rates were computed after subtracting the post-reinforcement pauses² from the fixed-ratio segments and were high for all subjects, ranging from an average rate of 185 responses per minute for S-2 to 154 responses per minute for S-1. The rates during variable-interval components displayed smaller variability both within and between subjects. Between subjects, the mean rate varied between 42.7 responses per minute for S-1 and 30.7 responses per minute for S-3.

Ratios expressing the response rate differential between the interval and ratio schedules were computed for each subject by dividing the mean of the four fixed-ratio run rates preceding probes by the mean of the four similar variable-interval rates. The ratios were 3.6, 5.1, 5.2, and 4.4 to 1 for Subjects 1 through 4 respectively. The compound stimulus rates were between the variable-interval and fixed-ratio rate limits in every case except for the tests following the last fixed-ratio component for S-1 and the first fixed-ratio component for S-3. In both cases the compound stimulus

rates were slightly below the adjacent variable-interval component rates.

There did not appear to be any consistent differences between the compound stimulus rates following ratio components as opposed to those following interval components for any of the rats. Also, there was no discernible interaction effect across subjects attributable to counterbalancing the tone and the light between the two reinforcement schedules. There was a general decline in compound stimulus rates over successive test periods for S-2 and S-4 which possibly suggests the presence of progressive extinction for these two subjects. However, these declines were paralleled by corresponding declines in baseline responding over the successive ratio components for S-4 and over the successive interval components for S-2. Thus, the gradual drop in compound stimulus test rates may merely reflect the similar decrease in rate in one of the reinforcement components. For S-1 and S-3, response rates during reinforcement components did not change progressively over successive periods and neither did the compound stimulus test rates.

DISCUSSION

This study demonstrated that response averaging occurred in the presence of compound stimuli that had been individually associated with reinforcement schedules resulting in moderate and high response rates. The findings not only extended the generality of Weiss' (1967) response-rate-differential account of averaging to the upper end of the response rate continuum but they also demonstrated that averaging can occur with substantially lower response rate ratios than the 18 to 1 ratios reported by Weiss. The response rate ratios ranging between 3.6 and 5.2 to 1 in this study were all sufficiently large to result in response averaging.

In addition to a higher response rate, the fixed-ratio schedule resulted in a correspondingly higher reinforcement rate than did the variable-interval schedule. Reinforcement rate ratios ranged between 2.2 and 3.8 to 1 in favor of the ratio schedule. While it is possible that reinforcement rate differences contributed to averaging, Weiss' (1964) findings mitigate against the strong influence of this factor. Weiss (1964) reported additive summation de-

²Fixed-ratio run rates were considered to provide a more appropriate baseline for comparison with the compound test rates than the overall fixed-ratio rates since the characteristic pause following reinforcement is primarily related to reinforcer delivery which was, of course, absent during the test probe. Furthermore, gross inspection of the cumulative records failed to reveal any evidence of sustained pauses during the test probes, which might be predicted if pausing were also under the control of the fixed-ratio associated discriminative stimulus in the stimulus compound.

Fig. 1. Compound stimulus response rates following directly preceding FR segments (CS^D_{FR}) and VI segments (CS^D_{VI}) together with response rates during the directly preceding reinforcement components. The data have been collapsed over four blocks of VI and FR component pairs in order of their occurrence during the two test days.

spite reinforcement rate differences between components (VI 30-sec and VI 75-sec) comparable to those reported here.

At a more molecular level of analysis, response averaging during a dual-stimulus compound test may represent averaging of two distinct response rates controlled by the separate stimulus elements of the compound rather than the emission of a steady intermediate rate. A number of studies (Blough, 1963; Cumming and Eckerman, 1965; Migler, 1964; Migler and Millenson, 1969) have demonstrated that organisms that had been pre-trained to respond to two values along the same stimulus continuum with different topographies along a response class continuum behaved as though each separate stimulus-response unit were functionally intact during generalization tests to intermediate stimulus values. Rather than controlling a new and intermediate response topography, each generalized stimulus governed the proportion of test time that the two acquired responses were emitted. Intermediate response values thus resulted as an artifact of sampling a mixture of two alternating response rates.

The compound stimulus studies have differed from those cited above in that the two training stimuli were usually selected from different modalities and were directly paired to create a dual-stimulus complex. Ray (1969) incorporated this feature in studying the effects of compounding separate color and line-tilt stimuli which, in some test combinations, governed opposing choice responses. An analysis of "errors" made by the subjects during initial conflict tests revealed that control over the subjects' responses switched back and forth between the two stimulus dimensions.

Although the cumulative records did not permit a decision on whether the averaging obtained in this study represented a process of alternation between the variable-interval and fixed-ratio stimulus-response units as suggested by the above studies, such a process would be consistent with the data presented here. If one assumes that the mean response rates during the variable-interval and fixed-ratio schedules were each accompanied by interresponse-time (IRT) distributions that were centered at different positions on the IRT continuum, one might expect an intermediate response rate to result during a compound stimulus test if the subject alternated between the two distribu-

tions. Had IRTs been recorded during the compound stimulus tests, the presence of both schedule-associated behaviors might have been identified from a bimodality in the IRT distribution, although a clear interpretation would have been confounded by the fact that ratio-like response bursts often occurred during the variable-interval stimulus component.

While the response rate ratios reported here were substantially smaller than those reported by Weiss (1967), in absolute terms the differences in response rate between the two schedules exceeded his. Thus, the question remains whether averaging depends upon the size of response rate ratios or absolute differences in rate between schedules.

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