SUMMATION OF RESPONDING MAINTAINED BY FIXED-INTERVAL SCHEDULES¹

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A light and tone were separately correlated with responding maintained by fixed-interval schedules, in which the level of responding varied continuously throughout the duration of the interval. Responding during the presence of the single stimuli and their compound was compared during the successive segments of the interval. The following results were obtained: (1) more responses were emitted during compounding than were emitted during either stimulus alone in all segments of the interval; (2) increases in the number of responses across the interval during compounding paralleled increases during single-stimulus presentations. The sum of the responses emitted during the single stimuli was similar to the number of responses emitted during compounding, suggesting that the response tendencies correlated with the single stimuli combined in a summative or additive fashion.

When responding is maintained in the presence of two separate stimuli, a higher level of responding may occur when the stimuli are combined. This is known as summation of responding. Although the phenomenon has been demonstrated frequently in classical (Hull, 1940; Grings and O'Donnell, 1956), instrumental avoidance (Miller, 1969*b*), and free-operant (Wolf, 1963; Weiss, 1964; Miller, 1969*a*) conditioning, the relationship between the level of response maintained under the single stimuli and their compound is yet to be systematically investigated.

In order to investigate the relationship between level of response to single stimuli and their compound, different response levels maintained by fixed-interval schedules were examined. A fixed-interval (FI) schedule is particularly suited to the problem at hand because it allows the opportunity to examine continuous variations in responding in the same animal and within each FI presentation. If the FI value is long enough, the FI "scallop" will develop. That is, during the initial phase of the interval, few or zero responses are emitted. As the interval progresses responding increases. By dividing each FI into successive segments of equal length, these changes in responding

can be monitored throughout the interval. If two different stimuli are correlated with each FI, then a comparison can be made between changes in responding across the interval during the single stimuli and their compound.

METHOD

Subjects

Four male Sprague-Dawley albino rats were maintained at 75% (350 g) of free-feeding weight during the experiment.

Apparatus

A standard Grason-Stadler operant chamber was used. It was housed in a chest that shielded it from external stimuli and placed in a room that was separated from the scheduling equipment. Two fans provided ventilation and a masking noise. A G.E. 10-w, 2 foot-candle houselight and a 1475-Hz, 96-db tone (re. 0.0002 dynes/cm²), 20 db above the 76-db ambient sound level in the apparatus, served as the stimuli. A Jackson audio oscillator served as the tone source. Amplitude of the tone was measured at the response lever with a General Radio Co. sound-level meter. Brightness of the light was measured at the response lever with a Weston Foot-Candle Meter.

Procedure

The rats were first shaped to bar press and each response produced 45-mg Noyes pellets. The schedule was then changed to a multiple

¹This research was supported in part by a grant from the Bureau of Faculty Research, Western Washington State College made to the senior author. Reprints may be obtained from Laurence Miller, Department of Psychology, Western Washington State College, Bellingham, Washington 98225.

FI-EXT schedule. Stimulus control over responding was established through discrimination training. Bar presses were reinforced on FI only when the light or tone was present; the absence of light or tone (S^A) indicated no availability of reinforcement. S^A intervened between each FI component and was initiated when reinforcement was presented. Occurrence of light or tone during each FI presentation was randomly determined, with approximately equal numbers of light and tone presentations occurring during each 1.75-hr session. The duration of S^A was varied randomly from one FI to the next by means of a tape programmer. Hence, occurrence of reinforcement did not indicate the length of the interval before the next reinforcement; only the light or tone served this function. A response during S^A stopped the tape programmer for 10 sec. Any other responses made during this 10-sec period recycled the 10-sec interval.

Three durations of FI were examined: FI 1-min (Subject 1); FI 2-min (Subjects 2 and 3); FI 3-min (Subject 4). Under FI 1-min the duration of S^A varied randomly from 15 to 55 sec; under FI 2-min and 3-min, S^A varied randomly from 30 to 170 sec. Subjects were run daily for about 30 days. By this time they had developed both stable and characteristic FI responding. Almost no responses were emitted during S^A , indicating that the discrimination between light or tone and S^A had developed (see Fig. 1).

Compound tests were then scheduled. The

light and tone were compounded during FI presentations when only one stimulus would normally appear. Reinforcement remained available during compound tests. The rat on FI 1-min was given five compound tests each session. Subjects on FI 2-min and FI 3-min were given four tests each session. The particular FI in which compounding occurred was randomly determined, and occurred on the average of every fifth or sixth FI presentation. Subjects were tested over four sessions, yielding a total of 20 compound tests under FI 1-min and 16 tests under FI 2-min and FI 3-min. In order to assess changes in responding throughout FI, FI 1-min was divided into six successive segments of 10 sec, FI 2-min into six segments of 20 sec, and FI 3-min into six segments of 30 sec. The mean number of responses emitted in each segment under the compound was compared with the mean number of responses emitted during those FI presentations in which only the light or tone appeared. Responses were counted only after the rats had received about 10 reinforcements.

RESULTS AND-DISCUSSION

Figure 1 presents a cumulative recording of one of the test sessions of each animal. The general effect of compounding is quite apparent: a marked increase in responding is maintained steadily throughout the interval until reinforcement is received. The form of the

Fig. 1. Sample cumulative records from one test session for each rat. The components in which the light and tone were compounded are denoted by the letter C. The plateaus represent S^A periods. The depressed parts of the curve represent responding under FI. The top record is from Rat 1 (FI 1-min), Session 4; the second from Rat 2 (FI 2-min), Session 3; the third from Rat 3 (FI 2-min), Session 2; and the fourth from Rat 4 (FI 3-min), Session 2.

curve is consistent and stable and does not demonstrate the variations and fluctuations noticeable in some of the curves generated during presentation of the single stimuli.

The results of the four sessions of compound testing for each animal are shown in Fig. 2. Session 1 only is depicted in the left panel. Each point here represents the total number

Fig. 2. Mean number of responses emitted to the compound and single stimuli for successive segments of time under each FI schedule. For FI 1-min, each segment equals 10 sec; for FI 2-min, 20 sec; for FI 3-min, 30 sec.

of responses emitted for all presentations of each of the three stimulus conditions for each segment divided by the respective number of presentations of each stimulus. The result is the mean number of responses emitted during

each segment. The data for the four test sessions combined are presented in the right panel. Each point here was derived by taking the mean of the total number of responses emitted during all presentations of each stim-

Fig. 3. Obtained relationship between the sum of the response levels to the single stimuli and the level of response to the compound.

ulus condition in each segment over the four test sessions. Quite clearly, the level of responding during compounding is a direct function of the level of responding to the single stimuli. Increases in responding during the single stimuli are for the most part paralleled by increases in responding during compounding. It should be noted, however, that the increase in responding during compounding across successive segments is generally considerably greater than the corresponding increase to the single stimuli.

The present data also allow further examination of the meaning of the term "summation" of responding. Summation seems to imply that the response tendency during compounding is a simple sum of the response tendencies to each single stimulus. However, a wide variety of relationships have been reported. The response level to the compound has been found to be greater than (Wolf, 1963; Weiss, 1964; Miller, 1969a), or lesser than (Hull, 1940; Kimble, 1961, p. 87) the response level produced by the sum of the single stimuli. In some studies, responding to the compound was intermediate between responding to the single stimuli (Weiss, 1967; Reberg and Black, 1969). Only Pavlov (1927) seems to have found that the compound was a simple sum of the single stimulus responses.

In order to examine this question further, the data from the present experiment were analyzed as follows (see Fig. 3): The mean number of responses emitted by each rat in each FI segment during compounding over Sessions 1 to 4 was plotted against the sum of the response levels in the corresponding segments for the single stimuli (see right-half of Fig. 1). The result is a scattergram of 24 single data points. From this scattergram a line of best fit was derived by the least squares

method. For comparison, the theoretical line indicating perfect additive summation is also plotted. This line would consist of a band of data points with slope 1.0, passing through the origin. This analysis suggests that the relationship between responding to the compound and to the single stimuli in this situation is a simple summation function. That other relationships have been found suggests that the function depends upon the type of conditioning paradigm, reinforcement contingencies, method of testing, *etc.* that are used.

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Received 9 June 1969.