**COMBINED-STIMULUS CONTROL AS A FUNCTION
OF THE RESPONSE RATE CONTROLLED BY
THE ABSENCE OF THE SINGLE STIMULI¹**

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Rat's bar-press responses were maintained at moderate rates during separate presentations of light and tone by separate but concurrent variable-interval schedules of food and shock presentation. The relative response rate maintained during light-out-no-tone was alternated in four successive phases: in Phases 1 and 3 responding was maintained at a higher rate than that during light and tone alone by a variable-interval food schedule, while in Phases 2 and 4 responding was reduced to a lower rate by a differential-reinforcement-of-other-behavior food schedule. In test presentations of light, tone and a light-plus-tone combination, administered at the end of each phase, the proportion of responses emitted during light-plus-tone was an inverse function of the relative response rate controlled by light-out-no-tone, indicating that the relative training response rate controlled by the absence of the single stimuli determined the control exerted by the combined stimuli. Different relative response rates maintained in training may also be partly responsible for previously observed differences in the form of generalization gradients following the establishment of multi-stimulus control.

When responding is conditioned during each of two single stimuli, the combination of both stimuli frequently controls either a higher (Emurian and Weiss, 1972; Meltzer and Freeman, 1971; Miller, 1969*b*, 1971; Riess, 1969; Wolf, 1963) or a lower (Miller, 1969*a*; Reberg and Black, 1969; Van Houten and Rudolph, 1971) response rate than either single stimulus. While the variables responsible for these seemingly discrepant findings remain unclear, it has been pointed out (Weiss and Emurian, 1970) that one procedural variable common to all of the studies may account for the different results. In all of the studies, a third stimulus condition, consisting of a period during which both single stimuli were simultaneously absent, was included in training along with the single-stimulus conditions. In the studies reporting a higher response rate during the combined stimuli, this period controlled a lower response rate than either single stimulus, while in studies reporting a lower re-

sponse rate during the combined stimuli, this period controlled a *higher* response rate than either single stimulus. Thus, the response rate controlled by the absence of both single stimuli, relative to that controlled by the presence of each single stimulus, was different in studies reporting higher *versus* lower response rates during the combined stimuli. The present experiment examined the possibility that this difference influences combined-stimulus control.

Unlike the previously cited experiments, the present study employed a design in which each subject served as its own control. Two conditions were successively alternated for the same subject, and the results obtained under one condition were compared with those obtained under the other. While this design contains a number of distinct advantages over the more conventional between-groups design (Sidman, 1960), it did not eliminate two procedural difficulties frequently encountered in examinations of stimulus control: maintaining response rates that are free of both ceiling and floor effects (Hearst, Besley, and Farthing, 1970) and maintaining similar rates of food presentation despite different rates of responding (Reynolds, 1961). While a number of techniques might be used to overcome the first difficulty, the present experiment used separate but concurrently operating variable-interval

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schedules of food and shock presentation during each of the single stimuli to generate moderate response rates that could easily be changed in either direction. The second difficulty was overcome by alternately using variable-interval (VI) and differential-reinforcement-of-other-behavior (DRO) schedules of food presentation during the absence of both stimuli. Since VI schedules deliver reinforcers dependent upon responding, while DRO schedules deliver reinforcers dependent upon not responding, the alternate use of these schedules made it possible to change response rates alternately during the absence of both stimuli while maintaining similar food presentation rates throughout the experiment.

Thus, in the present study, moderate response rates were maintained during each of two single stimuli while the relative response rate controlled by the absence of both stimuli was alternated in four successive phases. Test presentations of each single stimulus and their combination were administered after each manipulation to evaluate the effects on combined-stimulus control.

METHOD

Subjects

Three experimentally naive adult male hooded rats weighing about 350 g (free feeding) were trained and tested at 80% of their free-feeding weights.

Apparatus

Each of three operant conditioning chambers measuring 8 in. high by 8.5 in. long by 7 in. wide (20.3 by 21.2 by 17.8 cm) was composed of white translucent plastic side walls, aluminum front and rear walls, a clear plastic ventilated ceiling, and a floor consisting of 0.125-in. (0.3 cm) diameter stainless steel grids spaced 0.5 in. (1.3 cm) between centers. A Gerbrands microswitch bar was positioned on the right side of the front wall, and 45-mg Noyes pellets were delivered to a feeder trough located to the left of the bar. Each chamber was enclosed in a sound-attenuating chest and located in a room adjacent to that housing the solid-state equipment used to control it.

The 2000-Hz, 90-dB tone stimulus, measured at the bar with a Type 1565-A General Radio Sound Level Meter, was presented through a 8 in. (20 cm) speaker mounted directly above

the chamber. The ambient noise level in the chamber, with the exhaust fan running, was about 80 dB. The light stimulus was generated by two 25-w, 125-v bulbs, one horizontally mounted 4 in. (10 cm) from the center of each of the translucent side walls. These bulbs together produced 130.2 cd/m² measured with a Honeywell Pentax photometer positioned 5 in. (12.5 cm) from the side walls of the chamber. Also, continuous illumination was provided by a 7-w, 120-v bulb, operating at 3 w.

Constant current electric shock was generated by a Lehigh Valley Electronics 1531 shocker-scrambler and delivered to the grid floor, front and rear walls, and manipulandum. Shock intensities and durations, which differed for individual subjects, are specified in Table 1.

Procedure

Preliminary training. Bar pressing was initially shaped by successive approximations, and then maintained under a variable-interval schedule of food presentation in which the first response occurring an average of 15 sec after the last food presentation produced food (VI 15-sec). This schedule was operative during separate presentations of light, tone, and light-out-no-tone. The mean interval between scheduled reinforcers was gradually increased from 15 sec to 70 sec, at which point a VI schedule of shock presentation was introduced during light and tone, with the mean interval again being gradually increased from 15 to 70 sec. The food and shock schedules were controlled by two different channels of the same tape, with three different tapes being used in a nonsystematic order throughout the experiment. The distributions on the different channels were always out of phase with each other so that events were seldom scheduled simultaneously by both channels. Food and shocks scheduled but not presented were cancelled with each stimulus change.

The duration of light and tone presentations was varied from 2 to 5 min, and the termination of each of these was followed by a 1.5 to 4-min presentation of light-out-no-tone. Sequence of presentation of light and tone was randomized with the restriction that neither one be presented more than three times in succession. The 2.5 to 3 hr training sessions were conducted on the average of six days a week.

Phase 1: high-rate light-out-no-tone. Phase 1 began when the mean interval of both food and shock schedules reached 70 sec. Thus, the training conditions of the first phase involved a multiple schedule consisting of (a) separate but concurrent VI 70-sec food and VI 70-sec shock schedules during light, (b) separate but concurrent VI 70-sec food and VI 70-sec shock schedules during tone, and (c) a VI 70-sec food schedule during light-out-no-tone. Training continued until the following stimulus control criteria were met over five consecutive sessions: (a) an immediate and sustained increase in response rate in at least 80% of the light-out-no-tone presentations, (b) immediate and sustained decreases in response rates in at least 80% of the light and tone presentations, and (c) an average response rate during light-out-no-tone at least twice as high as the average rates during light and tone. During the session after these criteria were satisfied, each subject was given a 30 to 45 min warmup followed by a test to be described later. This completed Phase 1.

Phase 2: low-rate light-out-no-tone. Upon completion of the initial phase, a differential-reinforcement-of-other-behavior (DRO) schedule was substituted for the VI schedule during light-out-no-tone. On the DRO schedule, food was presented after a period of time in which no bar presses were emitted. The period of time required to pass without bar pressing ranged from 40 sec to 80 sec, and was varied within and between sessions so that food presentation rates remained equal during all three stimulus conditions. Training was continued until the following criteria were met over five consecutive sessions: (a) an immediate and sustained decrease in responding in at least 80% of light-out-no-tone presentations, (b) immediate and sustained increases in responding in at least 80% of light and tone presentations, and (c) an average response rate during light-out-no-tone that was not more than half the average rates during light and tone. When these criteria were met, a test identical to that in Phase 1 was administered.

Phases 3 and 4: replications. Phase 3, which consisted of a replication of Phase 1, followed Phase 2. Phase 4, which was a replication of Phase 2, began when Phase 3 was completed. Table 1 shows the number of sessions in each phase.

Testing. Each test consisted of 12 random-

Table 1
Shock Parameters and Sessions in Each Training Phase

Subject	Phase	Session	Shock Intensity (mA)	Shock Duration (sec)
W-2	1	41	0.15	0.2
	2	28	0.15	0.2
	3	30	0.15	0.2
	4	15	0.15	0.2
W-3	1	73	0.30	0.5
	2	35	0.30	0.5
	3	25	0.30	0.5
	4	10	0.30	0.5
W-4	1	76	0.15	0.6
	2	42	0.15	0.2
	3	42	0.15	0.2
	4	17	0.15	0.2

ized blocks of 1-min presentations of light, tone, and light-plus-tone. One food presentation was scheduled during each test stimulus at an interval equal within test blocks but varying across blocks. This procedure provided a schedule of food presentation in testing that was quite similar to that employed in training while ensuring that food was scheduled with equal frequency and at equal within-stimulus intervals for all three test stimuli. A 1-min period of light-out-no-tone followed each test stimulus and was associated with the same schedule as that in the phase immediately preceding testing.

Thus, test conditions differed from training conditions in the following ways: (a) a light-plus-tone component was added to the multiple schedule, (b) components were of shorter duration, (c) the food schedule was slightly modified to provide equal food frequencies in all stimulus conditions throughout the test, and (d) the shock schedule was not operative.

RESULTS

Training

Table 2 shows response rates in each component of the training schedule averaged over the last five sessions of each phase, and food rates in each component averaged over all sessions of each phase. Response rates in light and tone, and food presentation rates in light, tone, and light-out-no-tone, did not systematically change as a function of the schedule associated with light-out-no-tone; however, the response rate controlled by light-out-no-tone,

Table 2
Terminal Training Data for Individual Subjects

Subject	Phase	Responses per Minute			Food Presentations per Minute		
		Light	Tone	Light Out-No Tone	Light	Tone	Light Out-No Tone
W-2	1	7.6	7.4	31.3	0.71	0.74	0.77
	2	7.5	8.7	0.8	0.73	0.73	0.74
	3	7.5	6.9	24.4	0.77	0.76	0.77
	4	5.3	5.2	1.5	0.77	0.77	0.77
W-3	1	17.1	19.6	66.0	0.78	0.81	0.79
	2	14.1	16.0	3.2	0.79	0.80	0.79
	3	12.0	10.6	50.5	0.78	0.79	0.79
	4	14.7	11.6	1.9	0.78	0.80	0.81
W-4	1	11.2	11.1	35.1	0.76	0.75	0.75
	2	9.8	10.3	2.1	0.75	0.76	0.75
	3	10.3	11.0	23.0	0.75	0.76	0.76
	4	10.1	11.3	2.5	0.77	0.77	0.74

Note: Response rates represent averages of the final five training sessions for each subject in each phase. Food rates represent averages of all training sessions for each subject in each phase.

relative to that controlled by light and tone alone, changed appropriately with each successive phase. In Phases 1 and 3, light-out-no-tone controlled a higher response rate than either light or tone alone, while in Phases 2 and 4, light-out-no-tone controlled a lower response rate than either light or tone alone.

The cumulative records of Figures 1 and 2 are from each subject's final training session in Phases 1 and 2, respectively. The records of Figure 1 were representative of the performance of all subjects in the later training sessions of Phases 1 and 3, while the records of Figure 2 were representative of the performance of all subjects in the later training sessions of Phases 2 and 4. Figure 1 describes the immediate and sustained increase in response rate accompanying most presentations of light-out-no-tone in Phases 1 and 3, and the immediate and sustained decrease in response rate accompanying most presentations of light and tone. Figure 2 shows the immediate and sustained decrease in response rate accompanying most presentations of light-out-no-tone in Phases 2 and 4, and the immediate and sustained increase in response rates accompanying most presentations of light and tone. Together, Figures 1 and 2 depict the stimulus control exhibited before testing, and illustrate the different relative response rate controlled by light-out-no-tone in the different phases.

Testing

Figure 3 shows the proportion of responses emitted during light, tone, and light-plus-tone by individual subjects in successive tests. The most important findings, which are shown by successive changes in the height of the solid bars in Figure 3, may be described as follows. In Test 1, following training conditions in which light-out-no-tone controlled a higher response rate than either light or tone alone, each subject emitted a relatively small proportion of responses during the light-plus-tone combination. Reduction of the response rate controlled by light-out-no-tone increased the proportion of responses controlled by light-plus-tone in Test 2. Reinstatement of the relatively high response rate controlled by light-out-no-tone resulted in a return to the small proportion of responses controlled by light-plus-tone in Test 3, while a second reduction of the response rate controlled by light-out-no-tone again increased the proportion of responses controlled by light-plus-tone (Test 4). These changes were observed in each subject, and there was no overlap in the proportion of responses controlled by light-plus-tone in Tests 1 and 3 on the one hand (range across subjects = 12.5 to 24.3%), and Tests 2 and 4 on the other (range across subjects = 27.7 to 45.5%).

Fig. 1. Cumulative records from the final training session of each subject in Phase 1, during which light-out-no-tone controlled a higher response rate than either light or tone alone. Depression of the cumulative response pen indicates light-out-no-tone. When the response pen is elevated, presentations of light and tone are indicated by depression and elevation, respectively, of the baseline pen. Slash marks in either direction on the response pen indicate food presentations, while slash marks on the baseline pen denote response-contingent shocks.

Fig. 2. Cumulative records from the final training session of each subject in Phase 2, during which light-out-no-tone controlled a lower response rate than either light or tone alone. See Figure 1 for identification of stimuli, reinforcers, and shocks.

Figure 3 further indicates that when light-out-no-tone controlled a relatively high response rate in Tests 1 and 3, light-plus-tone controlled a lower response rate than either

light or tone alone for all subjects. However, when light-out-no-tone controlled a relatively low rate in Tests 2 and 4, light-plus-tone controlled a different response rate, compared to

Fig. 3. Percentage of responses emitted during each test stimulus by individual subjects in successive tests. Each row of histograms depicts the proportion of responses emitted by a single subject in each test stimulus in each successive test. The abscissa is labelled to show that light-out-no-tone controlled a higher rate of responding than light or tone alone in Tests 1 and 3, and a lower rate of responding in Tests 2 and 4.

light and tone alone, for each subject. In both Tests 2 and 4, the combined stimuli controlled lower response rates than the single stimuli for W-2, intermediate response rates for W-3, and higher response rates for W-4. Thus, even though each change in the relative rate controlled by light-out-no-tone produced a cor-

responding change in the absolute proportion of responses controlled by light-plus-tone, it did not always produce a corresponding change in the relative proportion of responses controlled by light-plus-tone.

Responses emitted during light-out-no-tone are not shown in Figure 3. Inclusion of these

Table 3
Test Response Rates for Individual Subjects
(Responses per Minute)

Subject	Test	Light-Out- No-Tone	Light	Tone	Light Plus Tone
W-2	1	39.7	40.5	25.8	16.7
	2	1.7	12.4	11.1	10.4
	3	34.7	15.4	13.4	6.4
	4	4.5	12.3	10.9	8.9
W-3	1	61.1	37.8	58.0	13.7
	2	4.4	40.7	32.4	39.2
	3	46.2	20.9	31.4	14.5
	4	5.4	35.7	32.9	35.5
W-4	1	39.7	26.9	33.7	19.5
	2	2.9	10.7	6.3	14.2
	3	29.2	15.4	8.8	6.2
	4	2.6	11.2	8.7	14.2

data, which systematically varied across tests, would have differentially influenced the proportion of responses calculated for the other three test conditions. However, Table 3 shows the response rates controlled by each of the four stimulus conditions presented in each test. The relative proportion of responses controlled by light-out-no-tone in testing was similar to that in training in 11 of 12 instances. The exception is the first test of W-2, in which light controlled a slightly higher response rate than light-out-no-tone.

While relative response rates in testing and training were similar in all but one case, Table 3 indicates that the performances observed in testing differed from those observed in training in a number of other ways. First, the response rates in testing were generally higher than those in training. This is most clearly shown by comparing the response rates during light and tone in the first test of each subject (Table 3) with the response rates during light and tone in the first training phase (Table 2). In each case, response rates in testing were more than twice as high as the average of the five immediately preceding training sessions. Second, response rates during light and tone were sometimes markedly different for the same subject in the same test, even though they had generally been quite similar in training. This was particularly evident in Test 3 of W-4, where light controlled a considerably higher response rate than tone. Finally, response rates during light and tone sometimes changed by a factor of two or more between tests for indi-

vidual subjects. This degree of variability, which was exemplified in the difference between response rates in Tests 1 and 2 for W-4, did not occur between the various training phases.

DISCUSSION

Each change in the relative response rate controlled by the absence of both single stimuli resulted in an inversely related change in the proportion of responses controlled by the combined stimuli. Increases in the rate controlled by the absence of both stimuli resulted in decreases in the proportion of responses emitted during the combined stimuli, while decreases in the rate controlled by the absence of both stimuli resulted in increases in the proportion of responses emitted during the combined stimuli. This finding indicated that the effects of combining single stimuli are influenced not only by the response rates maintained during each of the single stimuli (Miller and Ackley, 1970), but also by the response rate maintained in their absence. Thus, the relative response rate controlled by the absence of single stimuli must be taken into account when considering the effects of combining those stimuli.

The results may also suggest that the relative response rates maintained in training are partly responsible for previously observed differences in the nature of other behavioral phenomena resulting from the establishment of multi-stimulus control. For example, in what is frequently referred to as generalization gradient summation, the gradients of pigeons' key-pecking responses following equal training with two related stimuli have been reported to be either higher (Blough, 1969; Kalish and Guttman, 1957) or lower (Hoffman, Selekman, and Fleshler, 1966) at points between the two training stimuli than at adjacent points on either side of the training stimuli. Since the former studies maintained responding solely under schedules of food presentation, while the latter study also employed stimulus-contingent electric shock, discussions of the opposing effects have usually focused upon the methods by which stimulus control was established. However, these studies were also accompanied by other methodological differences. In the studies reporting enhanced gradients of responding, each single stimulus was

followed by a "blackout" period during which both single stimuli were absent and responses had no scheduled consequences. Since pigeons do not normally respond during such a period (Ferster and Skinner, 1957) it may be assumed that the response rate during the absence of both training stimuli, which was not reported by the authors, was lower than those during the presence of each stimulus. On the other hand, in the study reporting suppressed gradients of responding, each single stimulus was followed by a period during which both stimuli were absent and responses were maintained under a VI schedule of food presentation. In this case, the authors reported that the response rate during the absence of both training stimuli was *higher* than those during the presence of each stimulus (Hoffman, *et al.*, 1966). Thus, the proportion of responses emitted during intermediate stimulus points in a generalization test, like the proportion of responses emitted during the combined stimuli in a combined-stimulus test, has been inversely related to the relative response rate controlled by the absence of both training stimuli.

Peak shift represents another phenomenon in which different results have been accompanied by different relative response rates during training stimuli. In peak shift, points on the generalization gradient removed from one training stimulus in a direction away from the other training stimulus control either higher (*e.g.*, Hanson, 1959; Pierrel and Sherman, 1960; Rudolph and Honig, 1972; Terrace, 1968; Yarczower, Gollub, and Dickson, 1968) or lower (Guttman, 1965; Hendry, Switalski, and Yarczower, 1969) response rates than either of the training stimuli. While numerous experiments and discussions have focused upon the necessary and sufficient conditions for the occurrence of higher response rates during shifted stimuli (Bloomfield, 1969; Friedman and Guttman, 1965; Kalish, 1969; Terrace, 1966; 1968; Yarczower, *et al.*, 1968), the conditions responsible for *higher versus lower* response rates have received little attention. However, it may be noted that in the former case the peak has always been displaced from the stimulus controlling the highest response rate in training, while in the latter case the peak has always been displaced from the stimulus controlling the lowest response rate in training. Unfortunately, the two types of

peak shift, like the two types of generalization gradient summation, have been accompanied by other differences in addition to response rate relations. For example, control by the stimulus from which the peak of responding shifts (positive peak shift) has been established by schedules of food presentation (*e.g.*, Hanson, 1959), while control by the stimulus from which the peak of response suppression shifts (negative peak shift) has been established by either extinction (Guttman, 1965) or stimulus-contingent electric shock (Hendry, *et al.*, 1969). Furthermore, instances of positive peak shift have been accompanied by either equal food-presentation rates in both training stimuli (Terrace, 1968; Yarczower, *et al.*, 1968) or higher food-presentation rates in the displaced stimulus (*e.g.*, Hanson, 1959), while reports of negative peak shift have been accompanied by lower food-presentation rates in the displaced stimulus (*e.g.*, Guttman, 1965). Thus, it remains to be determined whether different relative response rates are responsible for, or merely correlated with, the opposing results. However, the present results, when both the method of establishing control by the single stimuli and the food-presentation rates were held constant, may suggest that relative response rates are an important factor.

In the present experiment, each change in the relative response rate controlled by the absence of both stimuli produced a corresponding change in the absolute proportion of responses emitted during the combined stimuli, but did not always produce a corresponding change in the relative proportion of responses controlled by the combined stimuli. Although for all subjects the combined stimuli controlled lower response rates than either of the single stimuli when the absence of both stimuli controlled the highest rate in training, for each subject the combined stimuli controlled different response rates, compared to the single stimuli, when the absence of both stimuli controlled the lowest rate in training. This latter result was obtained even though the relative response rates of all subjects in both training Phases 2 and 4 and Tests 2 and 4 were similar to those in previous experiments reporting higher rates during the combined stimuli than during either of the single stimuli (*e.g.*, Wolf, 1963). Thus, it appears that in addition to relative response rates, other factors must also be taken into account

when considering the effects of combining separately conditioned stimuli.

The present procedures differed from previous experiments reporting enhanced responding during the combined stimuli in at least one way that might account for the obtained results. In the present study, the two experimental conditions were successively alternated for the same subjects. While this within-subject design permitted each subject to serve as its own control, it also provided each subject in Phases 2 and 4 with a history of a relatively high response rate during the absence of the single stimuli, which was not experienced by subjects in the previous studies. Since the previous history of control exerted by a particular stimulus sometimes plays an important role in determining subsequent outcomes of training with that stimulus (Peterson, 1962), it is possible that the previous history of control exerted by the absence of both single stimuli was responsible for the differences between the results of Tests 2 and 4 of the present experiment and previous experiments involving similar relative response rates. Further experimentation is required to determine the likelihood that subjects without a previous history of a relatively high response rate during the absence of two single stimuli would exhibit enhanced responding to the combined stimuli under the conditions of Phases 2 and 4 of the present experiment.

The problem examined in the present study required that response rates during each of the single stimuli be free of both ceiling and floor effects while food presentation rates remained equal in all stimulus conditions. Thus, shock was employed to overcome a methodological difficulty, rather than to study its effects on combined-stimulus control. However, the results may have some bearing on a recent study of shock and combined-stimulus control reported by Van Houten and Rudolph (1971). These investigators observed a suppressed response rate during combined shock-associated stimuli when periods during which both stimuli were absent were shock-free and controlled the highest response rate in training, but not when such periods were omitted from the training schedule. From this they concluded that "...the presence or absence of punishment-free periods during training determines whether or not summation of punishment suppression occurs (p. 121)". The present data

are incompatible with such an analysis: shock-free periods were included in all four training phases, but the combined stimuli consistently controlled a lower response rate than the single stimuli only in the first and third tests. These data indicate that the presence of shock-free periods *per se* is not a sufficient condition for the occurrence of suppressed responding during combined shock-associated stimuli.

A final consideration concerns the differences observed between training and testing performances in the present study. It was noted that response rates during each of the single stimuli were generally higher in testing than in training, were sometimes widely discrepant within a single test, and were occasionally quite variable between successive tests. One of the major procedural differences between training and testing was the removal of shock during testing. Since elimination of shock typically increases responding, with the response rate immediately following shock removal frequently exceeding even the normal pre-shock rate (Azrin, 1960), it is likely that shock removal accounts for the generally enhanced response rates during testing. Furthermore, recent evidence suggests that the removal of shock may also generate variability in stimulus control: Stoddard and Sidman (1971) pointed out that extinction tests are likely to produce fluctuations in stimulus control since the correlation between stimulus control and response-dependent events breaks down in extinction. Thus, it is possible that the withdrawal of shock in testing contributed substantially to both the increased rate and the increased variability of responding during each of the single stimuli.

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