Bulletin of the Psychonomic Society
1977, Vol. 10 (2), 115-117

Free-operant compounding of low-rate stimuli

STANLEY J. WEISS
The American University, Washington, D.C. 20016

Five rats were trained on a three-component multiple schedule. Tone and light were each associated with differential reinforcement of low-rate contingencies where a response was reinforced only if minimum interresponse time requirements were met. The simultaneous absence of tone and light was associated with nonreinforcement (extinction). During stimulus compounding tests, significantly more responses were emitted to tone plus light than to either tone or light presented singly. This demonstrates additive summation for the first time under conditions where increased responding could decrease frequency of reinforcement on the baseline schedules maintaining responding in training.

A stimulus that controls a change in behavior as a result of its association with a contingency of reinforcement is called a discriminative stimulus (S^D). There have been many reports of the simultaneous presentation of two independently conditioned discriminative stimuli controlling more responding than either S^D presented alone. This response enhancement has been called additive summation.

The training paradigms employed by those investigators reporting summation have shared many common characteristics. They used three-component multiple schedules in which the stimuli to be compounded, usually tone and light, each came to control response rates higher than those during the simultaneous absence of tone and light, tone off and light out ($\overline{T} + \overline{L}$). Customarily, it was through nonreinforcement that the lowest response rate in training was acquired by $\overline{T} + \overline{L}$. However, a variety of different schedules have been used to maintain responding during each of the reinforcement-associated stimuli. For example, Meltzer and Freeman (1971) and Weiss (1964, 1969, 1971, Experiment 2) employed variable-interval schedules; Miller and Ackley (1970) used fixed-interval schedules; and Emurian and Weiss (1972) had tone and light each associated with free-operant avoidance. Thus, a good deal of schedule generality already exists in regard to the contingencies associated with the stimuli compounded in those studies reporting free-operant additive summation.

The current experiment seeks to extend this generality by having responding maintained during tone and light with a differential reinforcement of low rate (DRL) schedule. On this schedule a response produces food only if it is emitted at least a minimum specified time following the preceding response. Therefore, an increased rate to combined DRL S^Ds would reduce reinforcement frequency under the baseline training schedule. As examination of the schedules employed in the stimulus compounding experiments cited above would reveal, this has never previously been the case when additive summation has been reported.

This research was supported by Grants MH-13495 and MH-16853 from the National Institute of Mental Health, Public Health Service. The author would like to express his appreciation to John Monahan and Judith Roes for their capable assistance in conducting this experiment. Reprints may be obtained from the author, Department of Psychology, The American University, Washington, D.C. 20016.

METHOD

Subjects and Apparatus

Five naive adult male hooded rats, approximately 350 g at the start of deprivation, were trained and tested at 80% of their free-feeding weights. Water was continuously available in individual home cages.

The operant training chamber was 20.3 x 21.2 x 17.8 cm wide. Its side walls were white translucent plastic, while the floor and ceiling were hardware cloth. A microswitch manipulandum and food trough were mounted on the aluminum front wall. The tone was 2,000 Hz at 90-95 dB; the ambient noise level, with the exhaust fan on, was 80 dB. The light S^D, generated by two 25-W 120-V bulbs, one mounted 10 cm from each side wall, was 130.2 cd/m². A dim houselight was on continuously. Apparatus and stimuli are described in greater detail elsewhere (Weiss, 1969).

Solid state programming equipment was located in a room adjacent to that housing the training chambers. Reinforcers were Noyes 45-mg pellets.

Procedure

Training. All subjects were initially trained to approach the food trough when the feeder operated. Next they were shaped by the method of successive approximation to press the bar. The terminal training arrangement was then gradually approached. This was a three-component multiple schedule comprised of a DRL 18-sec component (tone or light), a DRL 25-sec component (light or tone), and a nonreinforced extinction period (S^Δ) associated with $\overline{T} + \overline{L}$. Only interresponse times of at least 18 and 25 sec were reinforced during the DRL 18-sec and DRL 25-sec periods, respectively. Duration of the DRL components varied within the limits of 3 to 5 min. Each DRL component was followed by $\overline{T} + \overline{L}$, while either tone or light could follow $\overline{T} + \overline{L}$. For the tone or light to appear, bar-pressing had to cease in $\overline{T} + \overline{L}$ for a minimum time, varied within the limits of 20 and 80 sec. Subjects 1, 5, 9, 10, and 15 received 28, 29, 30, 28, and 26 sessions, respectively, on this multiple DRL 18-sec DRL 25-sec extinction terminal training baseline.

Testing. Tone, light, and tone plus light (T + L) were presented on this stimulus compounding test. These stimulus conditions were presented for 60 sec in each of 28 block randomized replications, with a 20-sec $\overline{T} + \overline{L}$ period separating test stimuli. A sample test replication might consist of the following stimulus sequence: tone, $\overline{T} + \overline{L}$, T + L, $\overline{T} + \overline{L}$, light, $\overline{T} + \overline{L}$. Total test time was 112 min. Testing started after an animal had received approximately 50 pellets on its training schedule. Reinforcement was discontinued during the test.

RESULTS AND DISCUSSION

Table 1 shows that all subjects responded at a higher rate to the DRL 18-sec than to the DRL 25-sec S^D. There was clear discrimination between tone or light and $\overline{T} + \overline{L}$, especially after warm-up, with responses emitted infrequently during $\overline{T} + \overline{L}$.

Table 2 indicates that during the stimulus compounding test all subjects responded at the highest rate in T + L, followed, in turn, by their outputs to the DRL 18-sec and DRL 25-sec S^Ds, respectively. A treatments by subjects ANOVA of tone, light, and T + L test responses produced an $F(2,8) = 27.1$, $p < .01$. There were significantly more responses emitted to the combined S^Ds (T + L) than to either the DRL 18-sec or DRL 25-sec S^Ds ($p < .01$), with more responding to the DRL 18-sec S^D than to the DRL 25-sec S^D ($p < .05$).

Additive summation during stimulus compounding in those studies employing variable-interval (VI), fixed-interval, or free-operant avoidance schedules would not reduce, and might even increase, reinforcement frequency on these baseline schedules. This is not so under a DRL schedule, especially since few of the responses emitted to T + L occurred in "bursts." Only 10.1% of the T + L test responses were emitted within 3 sec of each other, a percentage not significantly different from the 18.3% to the DRL 18-sec S^D and the 14.1% to the DRL 25-sec S^D [$F(2,8) = 1.2$, $p > .3$]. This means that summation in the present experiment would have been "expensive" in terms of reinforcement reduction on the baseline schedule.

The present experiment reports, for the first time, that additive summation will occur to compounded stimuli even when the response increase could reduce the frequency of reinforcement under the schedules these stimuli were associated with in training. This is functionally comparable to the aversive effects of subtractive summation recently reported when stimuli associated with free-operant avoidance (FOA) were compounded. Weiss (1976) trained animals to avoid at lower rates in tone and in light, where responses postponed shocks for 25 sec, then in $\overline{T} + \overline{L}$, where they postponed shocks for 10 sec. During stimulus compounding tests the 25-sec FOA contingency was effective in tone, light, and T + L. On these tests, T + L controlled a lower avoidance rate than tone or light in all subjects, even though this prolonged subtractive summation led to a shock rate in T + L that was 250% to 500% higher than that in tone or light. It appears that the response and reinforcement associations responsible for these summative effects, once acquired, can sustain nonadaptive behaviors during stimulus compounding when responding is maintained by positive or negative reinforcement.

Table 1
Terminal Training Data: Responses and Reinforcements/Minute

	Responses Per Minute			Reinforcements Per Minute	
	DRL Schedule		Ext.	DRL Schedule	
Subject	18-sec Tone or Light	25-sec Light or Tone	$\overline{T} + \overline{L}$	18-sec Tone or Light	25-sec Light or Tone
1	3.1*	2.4†	0.3	2.1	1.1
5	3.0†	2.3*	0.6	2.2	1.1
9	3.0*	2.1†	0.5	2.1	1.3
10	2.3†	1.9*	0.5	1.8	1.3
15	2.9*	2.4†	1.0	1.9	0.9
Mean	2.9	2.2	0.6	2.0	1.1

*Note—Average of final four training sessions. *Tone †Light*

Table 2
Stimulus Compounding Test Results: Total Responses and Responses/Minute

	Stimulus Condition*			
Subject	T + L	DRL 18-sec S^D	DRL 25-sec S^D	$\overline{T} + \overline{L}$
1	2.5	1.3	1.1	.04
5	2.3	1.8	1.1	.29
9	1.9	1.7	1.1	.18
10	1.2	.4	.4	.04
15	1.4	.5	.4	.04
Mean	1.9	1.1	.8	.11
Mean %†	51.8	27.5	20.7	

**T + L = tone plus light; DRL 18-sec and DRL 25-sec S^Ds were tone or light; $\overline{T} + \overline{L}$ = light out/no tone.*
†Calculated by converting responses to the DRL 18-sec S^D, DRL 25-sec S^D, and T + L to a percentage of total (tone, light, and T + L) test responses for each subject, and then averaging over subjects.

On DRL schedules, chains of collateral or mediated behavior often assist the animal in refraining from responding during those times when a response would postpone rather than produce a reinforcement (Laties, Weiss, Clark, & Reynolds, 1965; Laties, Weiss, & Weiss, 1969). Hearst, Koresko, and Poppen (1964) postulated that those mediating behaviors interfere with exteroceptive stimulus control on the basis of significantly flatter generalization gradients after DRL than VI training. On the other hand, Yarczower, Gollub, and Dickson (1969) reported very similar relative generalization gradients after VI and tandum VI DRL training, indicating that comparable exteroceptive control, as revealed by a generalization measure, is possible after spaced and regular VI responding. Would this comparability of exteroceptive control also be revealed if response distributions during stimulus compounding were compared after VI and DRL schedule training?

When tone and light were each VI associated, in experiments otherwise procedurally similar to the present study (Weiss, 1969, 1971, Experiment 2), T + L, or its equivalent, controlled approximately 63% of total test responses, with the range over the 10 animals limited to 58%-71%. In the present experiment, where DRL-associated stimuli were compounded, T + L controlled 51.8% of the total test responses—11% less than VI-associated stimuli. However, the range of the T + L percentages over subjects in the current study does substantially overlap with those of the VI-trained animals referred to above. Subjects 1, 5, 9, 10, and 15 emitted 51.1%, 44.0%, 40.8%, 61.8%, and 61.3%, respectively, of their test responses to T + L. Thus, although it appears that there could be a tendency for the magnitude of summation to be lower when DRL-associated stimuli are compounded than when VI are, the stimulus compounding test distributions of individual animals might look similar after training on the different schedules.

If chains of collateral behaviors do play a role in an animal's timing behavior under DRL schedules, might the additive effects observed to T + L in the present experiment be due to the "novel" T + L test condition disrupting the animal's timing behavior, rather than to the properties conditioned to the stimuli compounded? Weiss' (1972, p. 197) results prove this disruption explanation unlikely. He trained a rat to respond during tone and during light on a low-rate food reinforcement schedule while $\overline{T} + \overline{L}$ response rate was higher than that to either tone or light. After this training, T + L controlled only one-half as many responses as the tone or light on a stimulus compounding test. In comparison, in the present experiment, where $\overline{T} + \overline{L}$ training rate was below that of tone or light, T + L controlled approximately twice the response output of tone or light. A disruption of timing behavior should not produce additive effects in one case and subtractive effects in another. When T + L was composed of two stimuli discriminative for rate increase, as in the present experiment, it controlled more responses than tone or light conditions that contained only one stimulus discriminative for an increase in rate. On the other hand, when T + L was composed of two stimuli discriminative for rate decrease, it controlled fewer responses than tone or light, conditions that contained only one stimulus discriminative for a decrease in rate. These differential results were forthcoming to T + L under the two baselines even though tone and light each controlled spaced responding in both. It was baseline rates in tone and light relative to those in $\overline{T} + \overline{L}$ that appeared important in determining the results of compounding. This supports, and increases the schedule generality of, Weiss' (1972) analysis of additive and subtractive summation resultants produced through stimulus compounding.

REFERENCES

Emurian, H. H., & Weiss, S. J. Compounding discriminative stimuli controlling free-operant avoidance. *Journal of the Experimental Analysis of Behavior*, 1972, **17**, 249-256.

Hearst, E., Koresko, M. B., & Poppen, R. Stimulus generalization and the response-reinforcement contingency. *Journal of the Experimental Analysis of Behavior*, 1964, **7**, 369-380.

Laties, V. C., Weiss, B., Clark, R. L., & Reynolds, M. D. Overt "mediating" behavior during temporally spaced responding. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 107-116.

Laties, V. C., Weiss, B., & Weiss, A. B. Further observations on overt "mediating" behavior and the discrimination of time. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 43-57.

Meltzer, D., & Freeman, B. Maintenance of response summation under conditions of minimum intensity. *Psychonomic Science*, 1971, **22**, 287-289.

Miller, L., & Ackley, R. Summation of responding maintained by fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 199-203.

Weiss, S. J. Summation of response strengths instrumentally conditioned to stimuli in different sensory modalities. *Journal of Experimental Psychology*, 1964, **68**, 151-155.

Weiss, S. J. Attentional processes along a composite-stimulus continuum during free-operant summation. *Journal of Experimental Psychology*, 1969, **82**, 22-27.

Weiss, S. J. Discrimination training and stimulus compounding: Consideration of non-reinforcement and response differentiation consequences of S^{Δ}. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 387-402.

Weiss, S. J. Stimulus compounding in free-operant and classical conditioning: A review and analysis. *Psychological Bulletin*, 1972, **78**, 189-208.

Weiss, S. J. Stimulus control of free-operant avoidance: The contribution of response-rate and incentive relations between multiple schedule components. *Learning and Motivation*, 1976, **7**, 477-516.

Yarczower, M., Gollub, L. R., & Dickson, J. F. Stimulus control and the response-reinforcement contingency. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 561-564.

(Received for publication March 25, 1977.)