

A further application of composite-stimulus control in additive summation

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Six rats were trained to leverpress on a three-component multiple schedule containing variable-interval (VI) 28-sec, VI 66-sec, and extinction components. Under this arrangement all subjects came to respond during the VI periods, while responding essentially ceased in the extinction associated stimulus. Tone and light ($T + L$) were both present during the VI 28-sec contingency and both were absent (tone off and light out, $\bar{T} + \bar{L}$) during the VI 66-sec contingency. For half the rats extinction was programmed in light ($L + \bar{T}$), for the other half extinction was programmed in tone ($T + \bar{L}$). A composite-stimulus analysis of the training conditions reveals that, for the $L + \bar{T}$ extinction rats, the composite composed entirely of stimulus elements associated with responding was $T + \bar{L}$ (tone), while for the $T + \bar{L}$ extinction rats this stimulus was $L + \bar{T}$ (light). In testing all subjects emitted the most responses to that composite stimulus composed entirely of elements discriminative for responding, rather than to the VI associated composites that had an element in common with the extinction component. That it was tone or light to which the subjects showed additive summation supports predictions from Weiss' (1969, 1972) composite-stimulus control model.

When tone and light are each discriminative for an increase in response rate over the rate maintained in their simultaneous absence, more responses are emitted to tone-plus-light on a stimulus compounding test than to tone or light alone (Miller & Ackley, 1970; Weiss, 1964; Wolf, 1963). This phenomenon has been termed additive summation and has been demonstrated in rats with leverpressing maintained by food. When the tone and light are treated as composite, rather than unitary, stimuli in this conditioning situation, a unique relationship is revealed between these stimuli and tone-plus-light. According to this composite formulation, the simultaneous absence of tone and light is identified as $\bar{T} + \bar{L}$, tone and light are considered as $T + \bar{L}$ and $L + \bar{T}$, respectively, and tone-plus-light is represented at $T + L$. Weiss (1969) pointed out that $T + \bar{L}$ and $L + \bar{T}$ each contained one element associated with an increase in response (T and L , respectively) and another associated with a decrease in response (\bar{L} and \bar{T} , respectively). In comparison, $T + L$, which controlled additive summation, was composed entirely of elements associated with response increase. This is shown in row 1 of Table 1. Weiss (1969) explored this notion of stimulus control further by training animals on a schedule where $T + \bar{L}$ and $L + \bar{T}$ were discriminative for response increase, but the composite associated with response cessation was $T + L$. As row 2 of Table 1 shows, under this arrangement the composite now composed entirely of elements

associated with response increase was $\bar{T} + \bar{L}$, and Weiss predicted that configuration would control additive summation. The prediction was confirmed. $\bar{T} + \bar{L}$ controlled approximately 60% of the $T + \bar{L}$, $L + \bar{T}$, and $\bar{T} + \bar{L}$ test responses. Moreover, this percentage to $\bar{T} + \bar{L}$ was substantially the same as that reported to $T + L$ in a comparably performed mirror-image experiment reported by Weiss (1971, Experiment 2).

Weiss (1972) argued that the generality of the model might be tested in those situations where composites other than $T + L$ or $\bar{T} + \bar{L}$ were associated with response

Table 1
Composite Representation of Stimuli Used in Stimulus Compounding Experiments

Composite Stimulus Associated With Response Cessation*	Discriminative for Response Increase*	Composite Composed Exclusively of Elements Associated With Response Increase*
Training		
1. $\bar{T} + \bar{L}$	$T + \bar{L}$ $L + \bar{T}$	$T + L$
2. $T + L$	$T + \bar{L}$ $L + \bar{T}$	$\bar{T} + \bar{L}$
3. $T + \bar{L}$	$\bar{T} + \bar{L}$ $T + L$	$L + \bar{T}$
4. $L + \bar{T}$	$\bar{T} + \bar{L}$ $T + L$	$T + \bar{L}$
Test		

* $\bar{T} + \bar{L}$ = tone off and light out
 $L + \bar{T}$ = light on and no tone

$T + \bar{L}$ = tone on and light out
 $T + L$ = tone plus light

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cessation. If $T + L$ and $\bar{T} + \bar{L}$ were discriminative for response increase, while $T + \bar{L}$ controlled cessation, the composite composed entirely of elements associated with response increase would be $L + \bar{T}$ (light), as shown in row 3 of Table 1. Row 4 in Table 1 shows that if $T + L$ and $\bar{T} + \bar{L}$ were discriminative for response increase but $L + \bar{T}$ was associated with response cessation, additive summation should occur to $T + \bar{L}$ (tone).

Meltzer and Masaki (1972) confirmed these extensions of a composite-stimulus control notion. However, the magnitude of the summative effects they reported to $T + \bar{L}$ and $L + \bar{T}$ was much less substantial than those reported by Weiss (1969, 1971, Experiment 2). Was this due to limitations in application of the model or differences in procedures? The present experiment explored these possibilities by employing procedures more comparable to those that have been shown to produce strong additive summation.

METHOD

Subjects

Six experimentally naive male hooded rats, about 350 g at the beginning of the experiment, were maintained at approximately 80% of their free-feeding weights. Water was continuously available in the individual home cages.

Apparatus

Three similar 20 x 21 x 17.5 cm operant chambers were employed, each with a microswitch lever and a food trough on the front wall. The side walls were white translucent plastic, the front and rear walls aluminum, and the ceiling perforated transparent plastic. The floor was composed of stainless steel rods. The chambers were placed in sound-attenuation chests described by Weiss (1970). The light stimulus was generated by two 25-W 120-V bulbs that provided approximately 130.2 cd/m². The tone was 2,000 Hz at 90-95 dB. A dim houselight was on continuously. Comparable apparatus and stimuli are described in greater detail elsewhere (Emurian & Weiss, 1972). Reinforcers were Noyes 45-mg rat pellets. The programming was done by a PDP-8/E computer located in a room adjacent to that housing the training chambers.

Procedure

Baseline training. The rats were magazine trained and shaped to press the lever during the first session. On the next session reinforcement was arranged according to a variable-interval (VI) 15-sec schedule. During Sessions 3 and 4 this was changed to VI 28-sec. Beginning on Session 5 a three-component multiple schedule composed of VI 28-sec, VI 66-sec, and extinction (S^Δ) periods was instituted. The values of VI 28-sec ranged from 1 to 80 sec. The range of VI 66-sec intervals was 1 to 180 sec. Tone and light ($T + L$) were *both* on during the VI 28-sec component, while *neither* light nor tone ($\bar{T} + \bar{L}$) was on during the VI 66-sec component. For Subjects 271, 272, and 273, light ($L + \bar{T}$) was the stimulus signaling extinction. For Subjects 274, 275, and 276, tone ($T + \bar{L}$) was on during extinction. The $T + L$ and $\bar{T} + \bar{L}$ components appeared in random order, but were always separated by the S^Δ condition. The duration of all components varied nonsystematically within the limits of 1 to 10 min. After 27 2- to 3-h sessions on this multiple schedule, a correction procedure was instituted in the extinction component to suppress persistent responding. The correction procedure required that responding cease in an extinction period for a time averaging 60 sec, varying within sessions between 30 and 100 sec, before one of the VI components would commence. Other features of the multiple schedule remained un-

changed. All subjects were trained on the multiple schedule until they satisfied the discrimination criteria described below. This required between 7 and 21 additional 2- to 3-h sessions.

Discrimination criteria. A subject was trained until for 4 consecutive days a visual inspection of cumulative records showed (1) an abrupt and sustained response rate increase upon at least 75% of the presentations of the reinforcement associated stimuli ($T + L$ or $\bar{T} + \bar{L}$), and (2) an abrupt and sustained response reduction upon at least 75% of the S^Δ presentations ($T + \bar{L}$ or $L + \bar{T}$).

Test. After the rat had met the discrimination criteria, a test was administered with food reinforcement discontinued. The test consisted of 13 block-randomized presentations of $T + L$, $\bar{T} + \bar{L}$, and the composite composed exclusively of elements associated with response increase ($T + \bar{L}$ for Subjects 271, 272, and 273; $L + \bar{T}$ for Subjects 274, 275, and 276). These stimuli were each separated by the animal's extinction-associated stimulus ($L + \bar{T}$ for Subjects 271, 272, and 273; $T + \bar{L}$ for 274, 275, and 276). Each stimulus was on for 2 min. The test began after an animal received 30 min of reinforced training on its terminal baseline schedule. It lasted 156 min.

RESULTS AND DISCUSSION

Terminal Baseline Training Performance

Table 2 shows that response rates in S^Δ were substantially lower than those in $T + L$ or $\bar{T} + \bar{L}$ for all subjects on their criterion sessions. Stimulus control was comparable for both groups. With the exception of Subject 272, all rats responded at appreciably higher rates in their VI 28-sec periods ($T + L$) than in their VI 66-sec periods ($\bar{T} + \bar{L}$).

Test Performance

Table 3 shows that all animals emitted the most test responses to the composite composed entirely of response associated elements, with the outputs to the VI 28-sec, VI 66-sec, and extinction (S^Δ) associated stimuli following in that order for each animal. In light of the rank-order consistency of the four test conditions over $L + \bar{T}$ and $T + \bar{L}$ extinction groups, all subjects were combined for a Friedman two-way ANOVA. This yielded a $\chi^2_r = 18.0$ that was significant at $p < .001$. A Wilcoxon test indicated that at the .05 level significantly more responses were emitted (1) to the composite

Table 2
Terminal Training Performance* (Responses Per Minute)

Subject	Stimulus and Schedule Conditions		
	VI 28-sec $T + L$	VI 66-sec $\bar{T} + \bar{L}$	Extinction $L + \bar{T}$ or $T + \bar{L}$
A. $L + \bar{T}$ Extinction Group			
271	34.4	18.5	2.6
272	20.0	22.1	3.7
273	11.0	5.8	1.2
B. $T + \bar{L}$ Extinction Group			
274	43.0	17.5	3.0
275	24.2	12.7	4.0
276	21.8	12.4	3.0

*The rates are averages of the final four training sessions after a 30-min warm-up.

Table 3
Test Responses

Subject	Stimulus Conditions						
	Compound of S ^D Elements Exclusively Associated With Responding		VI 28-Sec S ^D		VI 66-Sec S ^D		S ^Δ
			T + L		T̄ + L̄		L + T̄ or T + L̄
A. L + T̄ Extinction Group							
271	367	(62.6%)*	121	(20.7%)	98	(16.7%)	5†
272	303	(50.3%)	196	(32.5%)	104	(17.2%)	1.3
273	142	(56.8%)	86	(34.4%)	22	(8.8%)	2.3
B. T + L̄ Extinction Group							
274	348	(57.6%)	198	(32.8%)	58	(9.6%)	8.7
275	366	(52.9%)	276	(39.9%)	50	(7.2%)	15.3
276	186	(52.8%)	144	(40.9%)	22	(6.3%)	2.3
Mean	285.3	(55.5%)	170.2	(33.5%)	59	(11.0%)	5.8

*Numbers in parentheses are percentages calculated for each subject by dividing the responses to each separate stimulus (tone-plus-light, light out/no tone, and the "compound") by the sum total of responses to these stimuli, and multiplying by 100. †In order to equate for the time subjects spent in each condition, number of responses in this column is the total to S^Δ divided by three.

composed of response associated elements than to T + L, T̄ + L̄, or S^Δ, (2) to T + L than to T̄ + L̄ or S^Δ, and (3) to T̄ + L̄ than to S^Δ.

Figure 1 indicates that the additive effect was evidenced from the beginning of the test for both groups. In addition, the relative magnitude of this effect increased as the test progressed. Dividing the responses each rat emitted to the composite composed of response associated elements (T + L̄ or L + T̄) by the sum of the responses emitted to T + L and T̄ + L̄ yielded ratios that averaged 1:1 during the first four replications, while during the last four replications the average ratio was 3:1. For five of the six subjects this ratio was larger during the last four test replications than in the initial four, suggesting that the T + L̄ and L + T̄ composites were more resistant to extinction than T + L and T̄ + L̄.

The magnitude and intersubject consistency of the additive summation in both groups of the present experiment was close to that of previous studies showing summation to T + L (Weiss, 1971, Experiment 2) and T̄ + L̄ (Weiss, 1969), indicating that equivalent stimulus functions can be served by T, L, T̄, or L̄ composite elements on the type of baselines under consideration. This control appears to be determined by the specific contingencies associated with each element.

In the present experiment T + L̄ or L + T̄ controlled over 55% of the test responses, more than the combined total of those emitted to T + L and T̄ + L̄. In the Meltzer and Masaki (1972) study, T + L̄ or L + T̄ controlled only 39% of the test responses, 36% less than the combined total to T + L and T̄ + L̄. The current results suggest that those weak summative effects were due to the procedures Meltzer and Masaki used in training and testing rather than to differences in stimulus control processes operating when summation occurs to tone-plus-light as compared to tone or light. The

discriminative control in training appeared weaker in the Meltzer and Masaki study than in the present experiment. Unfortunately, they did not present rates to S^Δ for their individual subjects, but they did indicate that S^Δ controlled rates between 7.5 and 17.3 responses/min, while one subject even responded more frequently in S^Δ than in its VI components.

The probe test Meltzer and Masaki (1972) employed probably also contributed to the weakness of their results. On the extinction tests of the current experiment, the relative magnitude of the summative effect grew larger as the test progressed because responding in T + L and T̄ + L̄ appeared to extinguish more rapidly than that to T + L̄ or L + T̄. This differential extinction has also been indicated in other experiments reporting summative effects where an extinction test was used (Miller & Ackley, 1970; Weiss, 1964). In comparison, the probe tests employed by Meltzer and Masaki presented each test stimulus only once per session, interspersed among reinforced components. This would have retarded extinction to T + L and T̄ + L̄, which were nonreinforced only occasionally, while speeding up extinction to T + L̄ and L + T̄, which were always nonreinforced.

That powerful additive summation occurred to T + L̄ (tone) and L + T̄ (light) in the current experiment indicates that it is an oversimplification to view these as unitary stimuli, as is customarily the case. Rather, it might be more profitable to view the rates resulting in these situations as a "mix" of the behaviors conditioned to each composite element. A stimulus element discriminative for an increase in rate and an S^Δ element associated with response cessation were contained in T + L and T̄ + L̄ composites for both groups of the present experiment. However, the recombination of elements during the test created a composite composed entirely of response associated

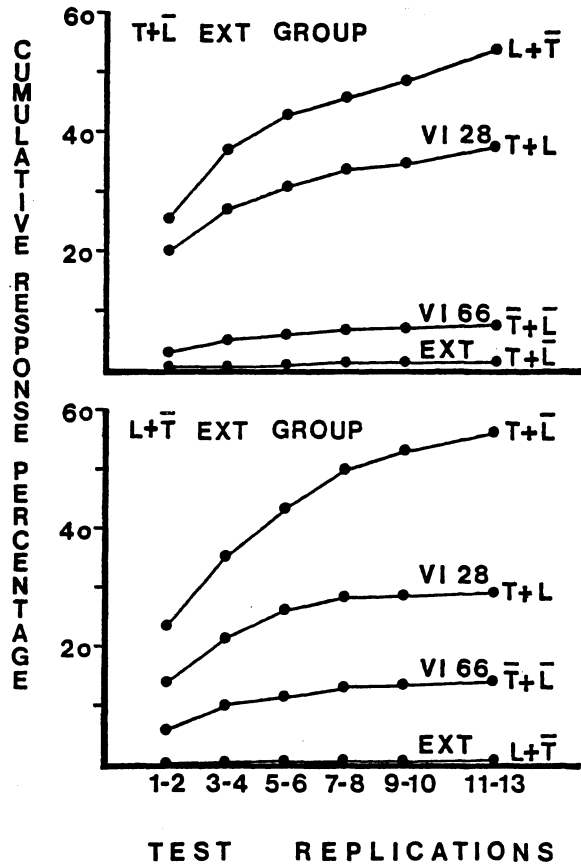


Figure 1. The mean percentage of responses emitted to each test condition accumulated over replications. The training schedule and the stimulus condition represented by each curve are indicated by the notation to the extreme right. The curves of L + T̄ (light) extinction Subjects 271, 272, and 273 are presented in the lower frame, while the curves for the T + L̄ (tone) extinction Subjects 274, 275, and 276 are presented in the upper frame. The entries in these figures were generated according to the following procedure. (1) A subject's response output to each stimulus condition was accumulated up to the indicated replication. (2) The accumulated responses were divided by that animal's total test responses. (3) These proportions were multiplied by 100. (4) Finally, the resulting percentages calculated for each subject at each point were averaged over subjects.

elements (T + L̄ or L + T̄). This composite, in every instance, controlled higher rates in testing than the VI associated composites, each of which contained a response cessation associated element. This could be interpreted as indicating that the response cessation associated elements were operating actively in VI components to depress the response rates, since their removal led to a rate increase. Thus, the results of the current experiment support Weiss' composite-stimulus control analysis. As he predicted (1972, pp. 194-195), training under any of the four arrangements shown in Table 1 can lead to roughly comparable additive summation to that test composite composed entirely of stimulus elements discriminative for an increase in responding, even those composites, such as tone or light, usually conceived of as unitary stimuli.

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