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WITHIN-SUBJECT REVERSIBILITY OF DISCRIMINATIVE FUNCTION IN THE COMPOSITE-STIMULUS CONTROL OF BEHAVIOR

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According to the composite-stimulus control model (Weiss, 1969, 1972b), an individual discriminative stimulus (S^D) is composed of that S^D's on-state plus the off-states of all other relevant S^Ds. The present experiment investigated the reversibility of composite-stimulus control. Separate groups of rats were trained to lever-press for food whenever a tone or a light S^D was present. For one group, the non-reinforced S^Δ condition was tone-and-light absence ($\overline{T}$+$\overline{L}$). Tone-plus-light (T+L) was S^Δ in the other group. On a ''stimulus compounding'' test that recombined composite elements, maximum responding occurred to that composite consisting only of elements occasioning response increase. That was T+L for the group trained with $\overline{T}$+$\overline{L}$ as S^Δ and $\overline{T}$+$\overline{L}$ for the group trained with T+L as S^Δ. The S^Δ composite was next reversed over groups in Phase 2. In Phase 2 tests, maximum responding that was comparable in magnitude to that of Phase 1 was again controlled by the composite consisting only of elements most recently occasioning response increase—whether T+L or $\overline{T}$+$\overline{L}$. The inhibitory conditioning history of both composite-elements currently occasioning responding did not weaken the summative effect. These results confirm and extend Weiss's composite-stimulus control model, and demonstrate that such control is fully reversible. We discuss how translating conditions of the stimulus-compounding paradigm to a composite continuum creates a functional and logical connection to intradimensional control measured through stimulus generalization, reducing the number of different behavioral phenomena requiring unique explanations.

Key words: composite-stimulus control, reversal learning, stimulus compounding, additive summation, composite-stimulus recombination test, stimulus generalization peak shift, rats

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The composite-stimulus control model (Weiss, 1969, 1972b) conceptualizes the presentation of an individual discriminative stimulus (S^D) as the composite of the on-state of that stimulus plus the off-states of all other relevant stimuli. Consider an experiment in which a tone and a light have been independently established as S^Ds occasioning lever pressing, while the simultaneous absence of these stimuli ($\overline{T}$+$\overline{L}$) is the S^Δ that signals extinction and occasions response cessation. Traditionally, presentation of such S^Ds would be described as unitary ''tone'' and ''light'' components. However, from the perspective of the composite-stimulus control model the tone is described in a binary manner as ''tone on, light off'' (T+$\overline{L}$) and presentation of the light is described as ''light on, tone off'' ($\overline{T}$+L).

According to the foregoing analysis and as shown in row 1 of Table 1, the ''tone'' and the ''light'' each contain one element controlling response increase (T when tone is the S^D, L when light is the S^D) and one element controlling response decrease ($\overline{L}$ when tone is the S^D, $\overline{T}$ when light is the S^D). This formulation also posits that the resulting behavior is a product of the subject sampling the on- and the off-states of each composite. Weiss (1969) pointed out that when the tone and the light are presented simultaneously (T+L), the resultant composite only contains elements discriminative for response increase and no elements occasioning response decrease. Consequently, greater responding is observed to the compound T+L than to the individual tone (T+$\overline{L}$) or light ($\overline{T}$+L) that each contain an S^Δ element controlling response cessation (Weiss, 1969, 1972b).

In a critical test of the composite analysis of stimulus control, Weiss (1969) performed an experiment where tone and light were inde-

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The principles of laboratory animal care as described in the *Guide for the Care and Use of Laboratory Animals* (National Academy of Sciences, 1996) were followed during this research.

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Table 1

Composite representation of stimuli used in stimulus compounding experiments that schematically specifies the "on" and "off" (overbar) states of the differentiated elements comprising a composite.

	Composite Stimulus		
	Associated With Response Cessation	Discriminative For Response Increase	Composed Exclusively of Elements Associated With Response Increase
	Training	Training / Test	Test
1.	$\overline{T}+\overline{L}$	$T+\overline{L}$ $\overline{T}+L$	$T+L$
2.	$T+L$	$T+\overline{L}$ $\overline{T}+L$	$\overline{T}+\overline{L}$

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

Note. It is assumed that behavior to a composite stimulus results from a subject sampling its elements such that more behavior would be produced when it is in the presence of two elements controlling an increase in response than when it is in the presence of one element controlling response increase and another response cessation (see Weiss, 1972).

pendently established as S^Ds for food-reinforced lever pressing. However, in contrast to the usual arrangement, the S^Δ was T+L (rather than $\overline{T}+\overline{L}$, see row 2 of Table 1). This meant that tone ($T+\overline{L}$) and light ($\overline{T}+L$) would again each contain one element discriminative for response increase ($\overline{L}$ and $\overline{T}$, respectively) and one element discriminative for response decrease (T and L, respectively). With such training, the composite model predicts that $\overline{T}+\overline{L}$ (all stimuli off) would produce more responding than the tone or light alone since the $\overline{T}+\overline{L}$ composite only contains elements associated with response increase. This prediction was confirmed by Weiss (1969) and extended to the summation of conditioned suppression by Weiss and Emurian (1970). A more complete description of this formulation with additional empirical confirmations can be found in Weiss (1978) and Weiss and Schindler (1987). Further discussion of configuration and combination laws in conditioning with compound stimuli can be found in Kehoe and Gormezano (1980).

Previous experiments have found that the stimulus compounding assay is sensitive to conditioning history effects that are not evident from the baseline stimulus control of behavior. For example, in one group of rats, Weiss and Schindler (1985) established a tone as an S^D for lever pressing maintained by free-operant avoidance and a light as a safety signal (avoidance contingency not in effect). Subsequently, compounding the light with the tone resulted in a 50% reduction below avoidance responding occasioned by tone alone. However, in a second group where lever pressing was also maintained by free-operant avoidance in tone, the light had previously served as an S^D for shock avoidance before it was converted into a safety signal. In this "history" group, the light had no effect on responding occasioned by the tone on a stimulus compounding test. This occurred despite the fact that the light alone controlled near zero responding in both groups during baseline sessions immediately preceding the stimulus compounding test as well as during the compounding test. That stimulus compounding tests were sensitive to residual effects of past conditioning history not apparent in current baseline behavior suggests that some conditioning experiences may be irreversible.

The present experiment explored the within-subject reversibility of composite-stimulus control for the first time. All rats were trained on a procedure where a tone and a light were independently established as S^Ds for food-reinforced lever pressing. For half the rats, S^Δ was $\overline{T}+\overline{L}$ and for the other half S^Δ was T+L (rows 1 and 2 of Table 1, respectively). After stimulus control was well established, a test was administered where the composite containing only elements associated with response increase (T+L or $\overline{T}+\overline{L}$) was presented for the first time to each group on a stimulus compounding (or what might more operationally be called a "composite-element recombination") test. This is the first time both of these composite training arrangements were part of the same experiment, thus permitting direct comparisons not possible heretofore.

Subsequently, in Phase 2 the same rats continued on the discriminative baseline, until they satisfied the discrimination criteria of Phase 1, but with the opposite composite as S^Δ (i.e., for rats where T+L was originally S^Δ, now $\overline{T}+\overline{L}$ was S^Δ and vice versa). Then, the reversibility of composite-stimulus control was examined with a second composite-element recombination test. In this phase of the experiment, animals should continue to respond in baseline training sessions during the tone alone ($T+\overline{L}$) and the light alone ($\overline{T}+L$) because responding will continue to be reinforced in these composites. With sufficient training, it is expected that animals will learn to stop responding in the new S^{Δ} composite consisting of elements that previously occasioned responding. Of particular interest are the results of the composite-element recombination tests administered at the end of this reversal training phase. Now the test composite contains elements associated only with response increase during the immediately prior baseline training sessions, but these elements have a Phase 1 history of nonreinforcement that controlled response cessation. Will the additive summation be of the same magnitude as in Phase 1, or will the inhibitory conditioning history of both composite elements that currently occasion responding lead to a weaker summative effect?

METHOD

Subjects

Six adult male Long-Evans rats served as subjects. They were individually housed in plastic cages with cedar chip bedding in a colony room that had a 12-hour light/dark cycle (lights on at 0800). Training sessions lasting approximately 2–3 hours were conducted between 1900 and 2200. Body weights were maintained at 80% of ad lib (approximately 380 g) by feeding rats approximately 9 g of rat chow following their training sessions. Water was available continuously in the rats' home cages. Training sessions were conducted 4–5 days per week.

Apparatus

Training took place in six operant chambers that were enclosed in sound attenuation chests (Weiss, 1970). Each chamber was 20 cm high, 23 cm long, and 18 cm wide and had aluminum front and rear walls, white translucent plastic side walls, and a grid floor. A response lever and food trough was located on the front wall of the chamber. The tone (approximately 2000 Hz and 85 dB) was delivered through a speaker mounted 21.5 cm above the chamber and inside of the sound attenuation chest. The light was provided by two 15-cm, 25-W, 120-V tubular light bulbs located 10 cm outside of the chamber's side walls. The level of illumination provided by these light bulbs was approximately 130 cd/m when measured at the center of the side walls. Reinforcers were 45-mg Bioserve pellets based on the traditional P.J. Noyes formulation. Experimental events were controlled by a MED Associates (St. Albans, VT) computer system located in a room adjacent to the one where the training chambers were located. Cumulative recorders used to monitor rats' ongoing behavior were also located in this room.

Procedure

Lever-press acquisition. To magazine train rats, food was presented on a variable-time (VT) 120-s schedule. In addition, lever presses produced food on a fixed-ratio (FR) 1 schedule. The VT schedule was discontinued once a rat emitted at least eight responses. The FR value was gradually increased over sessions from 1 to 10. Then, a variable-interval (VI) 60-s (range: 2–158 s) schedule was introduced. The tone stimulus was on continuously during the foregoing sessions. Once regular responding (as judged by the experimenter's examination of cumulative records) was observed on this VI 60-s schedule, lever-press training with the light stimulus began. With the light stimulus present continuously (and the tone off), rats were trained to lever-press on an FR schedule that was gradually increased from 1 to 10. Then, a VI 60-s schedule was implemented. Once stable responding on this VI 60-s schedule was observed, discrimination training began.

Phase 1: Discrimination training. Rats were randomly assigned to one of two counterbalanced conditions based on which composite was initially trained as S^{Δ}. For half the rats, S^{Δ} was the absence of both tone and light ($\overline{T}+\overline{L}$). For the other half, S^{Δ} was the simultaneous presence of both tone and light (T+L). During discrimination training, approximately 60-s (range: 30–120) periods of tone alone ($T+\overline{L}$) or light alone ($\overline{T}+L$) alternated with S^{Δ} periods also lasting 60 s on average (range: 40–90 s). Each type of S^{D} component had an equal probability of following the S^{Δ} component with the restriction that there were no more than three consecutive S^{D} components of the same type. During the S^{D} components, lever presses were reinforced according to a VI 60-s schedule. During S^{Δ} components, lever presses were not reinforced (extinction: EXT). To promote response cessation in S^{Δ}, and to prevent adventitious reinforcement, during the final 10 s of S^{Δ} components a lever press delayed onset of the next S^D component by 10 s. This interval was gradually increased over sessions to 60 s. Sessions lasted 2–3 h and contained 30 to 60 alternations of S^D and S^{Δ} components, with the number of alternations affected by the extent to which responses in S^{Δ} increased the length of that component.

Rats were trained on this three-component multiple (mult) VI 60-s VI 60-s EXT schedule for at least 16 sessions and until, for 3 consecutive sessions, (1) response rates in S^D components were at least 10 times those in the S^{Δ} component, and (2) response rates in the tone and the light S^D components did not differ by more than a 2:1 ratio.

Phase 1: Composite-element recombination (stimulus compounding) tests. After meeting these criteria, rats received their first composite-element recombination test. The test session was preceded by approximately 30 min of reinforced training on the rat's terminal baseline multiple-schedule arrangement as described above. No food was presented during the test session which consisted of 12 60-s components each of tone alone, light alone, and the recombined composite containing only elements controlling response increase (see Table 1). The order of these components was randomized in three-component blocks. Within these blocks, each component was separated by a 60-s period where the composite that served as S^{Δ} during training was presented. Because there were three such S^{Δ} periods per block, each block was 6 min and the entire test (12 blocks) 72 min. After the first test session, rats were retrained on their baseline mult VI 60-s VI 60-s EXT schedule until meeting the discrimination ratio criteria again, but with no minimum number of sessions required. Following retraining, each rat completed a second composite-element recombination test identical to the first one.

Phase 2: Composite S^{Δ} reversal training. Rats were next trained on a mult VI 60-s VI 60-s EXT schedule like that in Phase 1 except that the S^{Δ} composite was reversed for each rat. That is, for those rats where S^{Δ} was T+L in Phase 1, now $\overline{T}+\overline{L}$ was S^{Δ}. For those rats where S^{Δ} was $\overline{T}+\overline{L}$ in Phase 1, now T+L was S^{Δ}. All other aspects of training were the same as in Phase 1, with lever pressing continuing to be reinforced in tone ($T+\overline{L}$) and in light ($\overline{T}+L$). Rats were trained on this procedure until satisfying the Phase 1 discrimination criteria.

Phase 2: Composite-element recombination tests. Next, rats completed a composite-element recombination test wherein the recombined composite was now composed of elements that differentially occasioned response increase in Phase 2 training. The features of this test were the same as described above. After this test, rats were retrained on their mult VI 60-s VI 60-s EXT schedule until meeting the discrimination ratio criteria (minus the minimum 16 session requirement). Finally, each rat completed a second composite-element recombination test.

RESULTS

Training

Table 2 shows, for individual rats, the number of sessions required to meet the training criterion of three consecutive sessions with responding at least 10 times faster in S^D than S^{Δ} components. For the training which preceded the first composite-element test rats originally trained with $\overline{T}+\overline{L}$ as S^{Δ} required an average of 21.7 (4.3 SEM) discrimination sessions and the rats originally trained with T+L as S^{Δ} required a comparable 19.7 (1.9 SEM) sessions. In Phase 2, those rats whose S^{Δ} was changed from $\overline{T}+\overline{L}$ to T+L required an average of 37.3 (10.3 SEM) sessions to reach criterion while those rats whose S^{Δ} was changed from T+L to $\overline{T}+\overline{L}$ required an average of 40.7 (13.7 SEM) sessions to reach criterion. Overall, the two groups appeared comparable in (1) sessions to learn the original discrimination in Phase 1, and (2) the sessions required to reverse the discrimination in Phase 2—with about twice as many sessions required to reverse the discrimination as to acquire it originally.

Individual rats' component response rates averaged over the final three criterion sessions are shown in Table 2. Criterion rates prior to Phase 1 tests are presented to the left and rates prior to Phase 2 tests (after S^{Δ} was reversed for each rat) are presented to the right. Stimulus control prior to both composite-element recombination tests is clear in all subjects. Rates

Table 2

Number of sessions required to meet criterion plus individual subjects' average responses/min (SEM) over baseline criterion sessions preceding the two composite-element recombination tests in each phase.

	Phase 1					Phase 2				
Rat	Test	Sessions	Tone (T+$\overline{L}$)	Light ($\overline{T}$+L)	S^{Δ} ($\overline{T}+\overline{L}$)	Test	Sessions	Tone (T+$\overline{L}$)	Light ($\overline{T}$+L)	S^{Δ} ($\overline{T}+\overline{L}$)
K1	1	19	33.4 (4.5)	31.5 (2.9)	1.5 (0.5)	1	26	9.2 (2.3)	6.7 (1.7)	0.5 (0.2)
	2	17	17.9 (5.0)	22.5 (5.9)	1.0 (0.4)	2	7	9.2 (3.0)	6.6 (0.8)	0.4 (0.1)
K3	1	16*	34.5 (4.7)	48.0 (8.1)	2.6 (0.9)	1	28	30.3 (1.1)	20.4 (1.5)	1.9 (0.2)
	2	4	39.9 (5.0)	46.0 (3.0)	2.4 (0.6)	2	17	58.5 (11.4)	32.3 (2.5)	2.4 (0.3)
K5	1	30	35.6 (3.4)	37.2 (4.4)	1.5 (0.0)	1	58	23.3 (1.8)	11.7 (1.0)	0.7 (0.1)
	2	5	25.1 (2.9)	32.4 (3.3)	1.3 (0.5)	2	16	19.0 (2.3)	9.4 (0.6)	0.8 (0.0)
	Test	Sessions	Tone (T+$\overline{L}$)	Light ($\overline{T}$+L)	S^{Δ} (T+L)	Test	Sessions	Tone (T+$\overline{L}$)	Light ($\overline{T}$+L)	S^{Δ} ($\overline{T}+\overline{L}$)
K2	1	22	27.4 (2.9)	21.2 (0.8)	1.0 (0.2)	1	29	7.1 (0.8)	9.3 (1.5)	0.6 (0.6)
	2	6	19.2 (2.2)	17.5 (3.8)	1.2 (0.3)	2	3	14.7 (3.6)	13.2 (1.8)	1.0 (0.3)
K4	1	21	7.1 (3.3)	6.4 (1.6)	0.3 (0.1)	1	25	5.8 (0.6)	6.3 (0.6)	0.5 (0.1)
	2	5	8.0 (0.5)	7.2 (0.3)	0.3 (0.1)	2	9	10.0 (0.9)	9.0 (1.7)	0.6 (0.2)
K6	1	16**	17.8 (2.3)	14.0 (0.5)	0.4 (0.1)	1	68	14.7 (3.1)	20.4 (1.8)	1.1 (0.1)
	2	10	14.6 (2.0)	11.3 (0.9)	0.4 (0.1)	2	42**	15.6 (2.5)	23.4 (5.4)	1.8 (0.2)

* K3 reached the initial 10:1 discrimination criterion of Phase 1in 12 sessions

** K6 reached the initial 10:1 discrimination criterion of Phase 1in 13 sessions

*** K6 had only achieved a 8.5:1 discrimination ratio after 42 sessions and was tested at that ratio because it appeared to have reached asymptote.

in S^D were in all cases higher in Phase 1 for those rats originally trained with $\overline{T}+\overline{L}$ as S^{Δ}.

Testing

On the basis of the overall comparability over tests within phases (described below), data from tests 1 and 2 were combined in Figure l. Each panel of Figure 1 presents the across-subject mean ($\pm$SEM) percent of all test responses emitted in each stimulus component ([responses in component / sum of responses in all components] $\times$ 100). This percentage measure allows individual differences in response rates (see Table 3) to be weighted equally over subjects. The left and right columns of graphs in Figure 1 show responding in Phases 1 and 2, respectively. The upper two graphs in each column separate groups on the basis of their training S^{Δ} (indicated to the left on the x-axis). The bottom panels of Figure 1 present the combined results for counterbalanced subgroups in Phases 1 and 2.

As was true at the termination of training, responding in the S^D components of the test sessions greatly exceeded that in the S^{Δ} components. This occurred regardless of the S^{Δ} stimulus configuration or phase. As the bottom frames of Figure 1 illustrate, across phases rats responded two to three times as much during the recombined composite, composed solely of elements discriminative for response increase, as during the tone or the light alone. As may be seen in Table 3, the relations observed in the group data held true for individual rats as well. In Phase 1, response rates in the recombined test component exceeded that observed within the same session in either S^D component in 24 of 24 comparisons. In Phase 2, this relation was observed in 23 of 24 comparisons.

The consistency in the percentage of test responses controlled by the recombined composite over subjects, both within and between experimental phases, is noteworthy. In Phase 1, rats originally trained with the $\overline{T}+\overline{L}$ S^{Δ} emitted an average of 57.2% (4.9% SEM) of their test responses to the recombined composite on test 1 and an average of 61.3% (1.4% SEM) on test 2. For the rats originally trained with T+L as S^{Δ}, these Phase 1 test 1 and test 2 percentages were 60.3% (6.4% SEM) and 59.5 (5.8% SEM), respectively, as shown in the lower-left quadrant of Table 3.

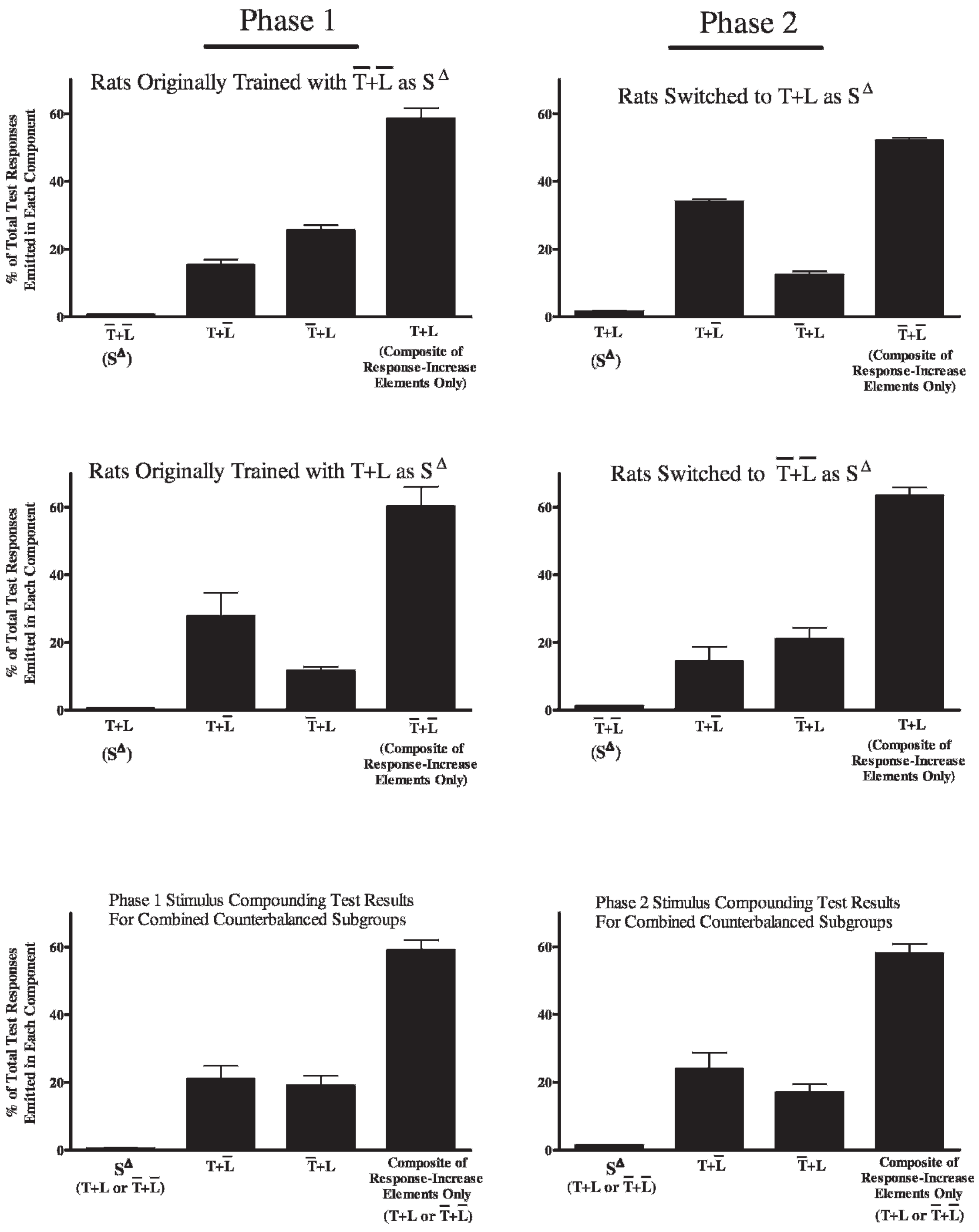

Fig. 1. Across-subject mean (±SEM) percent of responses emitted in each component of the composite-element recombination test sessions ([response rate in condition / sum of response rates in all conditions] × 100). The left and right column of graphs correspond to data collected in Phases 1 and 2, respectively. The top two graphs in each column present results for rats exposed to the S^{Δ} stimulus shown to the left on the x axis in each graph. The bottom row presents combined results for counterbalanced subgroups of each phase.

Table 3

Composite-element recombination test results of individual rats presented as responses/min in S^{Δ}, tone, light, and the recombined test composite from tests 1 and 2 from each phase. The percentage of total test responses emitted in the recombined test composite is also presented (in parentheses). All tests were conducted in extinction.

	Phase 1					Phase 2				
Rat	Test	S^{Δ} ($\overline{T}+\overline{L}$)	VI S^{D} ($T+\overline{L}$)	VI S^{D} ($\overline{T}+L$)	Recombined Composite ($T+L$) Rate (%)	Test	S^{Δ} ($T+L$)	VI S^{D} ($T+\overline{L}$)	VI S^{D} ($\overline{T}+L$)	Recombined Composite ($\overline{T}+\overline{L}$) Rate (%)
K1	1	0.1	13.3	14.2	31.4 (53.4)	1	0.3	8.8	2.0	8.1 (42.2)
	2	0.2	3.3	10.2	19.4 (58.6)	2	0.2	4.4	3.5	11.3 (58.1)
K3	1	0	5.8	9.9	31.8 (66.9)	1	1.2	12.4	4.3	19.8 (52.5)
	2	0.3	6.4	12.6	32.2 (62.5)	2	1.0	24.9	6.8	36.3 (52.6)
K5	1	0.7	14.7	25.8	43.2 (51.2)	1	0.2	5.3	2.8	14.2 (63.1)
	2	0.8	6.8	11.8	38.2 (62.8)	2	0.6	12.8	4.1	15.3 (46.6)
		S^{Δ} ($T+L$)	VI S^{D} ($T+\overline{L}$)	VI S^{D} ($\overline{T}+L$)	Recombined Composite ($\overline{T}+\overline{L}$) Rate (%)		S^{Δ} ($\overline{T}+\overline{L}$)	VI S^{D} ($T+\overline{L}$)	VI S^{D} ($\overline{T}+L$)	Recombined Composite ($T+L$) Rate (%)
K2	1	0	11.8	4.2	27.8 (63.5)	1	0.3	2.0	2.8	7.8 (60.5)
	2	0.2	7.6	3.0	13.9 (56.3)	2	0.1	4.3	3.2	10.0 (56.8)
K4	1	0.1	2.2	1.8	9.3 (69.4)	1	0.3	1.4	2.0	6.6 (64.1)
	2	0.1	1.5	1.6	7.7 (70.6)	2	0.1	2.9	2.1	10.4 (67.1)
K6	1	0.1	12.2	2.4	13.6 (48.1)	1	0.2	1.6	4.6	11.4 (64.0)
	2	0.1	7.0	2.8	10.5 (51.5)	2	0.2	1.1	7.9	18.5 (66.8)

In Phase 2, rats originally trained with the $\overline{T}+\overline{L}$ S^{Δ}, and now switched to the T+L S^{Δ}, emitted 52.6% (6.0% SEM) of their test 1 responses to the recombined composite and 52.5% (3.3% SEM) in that condition on test 2. For those rats originally trained with T+L as S^{Δ}, and switched to the $\overline{T}+\overline{L}$ S^{Δ}, these Phase 2 test percentages were 62.9% (1.2% SEM) and 63.6% (3.4% SEM), respectively.

Table 3 reveals that changes in the on/off state of the light controlled higher response rates than changes in the on/off state of the tone regardless of whether T+L or $\overline{T}+\overline{L}$ acted as the S^{Δ} composite. For example, subjects K1, K3, and K5 who were originally trained with $\overline{T}+\overline{L}$ as S^{Δ} had higher test response rates in $\overline{T}+L$ than in $T+\overline{L}$. However, after reversal training, when T+L was S^{Δ}, all of these subjects displayed higher test response rates to $T+\overline{L}$ than to $\overline{T}+L$. The same effect was also observed in subjects K2, K4, and K6, for whom S^{Δ} was originally T+L and then reversed to $\overline{T}+\overline{L}$. This is seen graphically in Figure 1. A similar, but smaller, effect is also evident in the training response rates presented in Table 2. Potential reasons for this difference are discussed below.

DISCUSSION

The present experiment confirmed and extended Weiss's composite-stimulus control model (Weiss, 1969, 1972b, 1978; Weiss & Schindler, 1987). Additive summation was found in the presence of a composite stimulus containing only elements associated with response increase, whether that composite consisted of the simultaneous presence or absence of the tone and the light. That is, when tone ($T+\overline{L}$) and light ($\overline{T}+L$) each independently occasioned lever pressing, maximum responding was found to T+L when $\overline{T}+\overline{L}$ was the S^{Δ}. However, when T+L was the S^{Δ}, and tone and light continued to occasion lever pressing, maximum responding was observed in $\overline{T}+\overline{L}$. For the first time, the present experiment demonstrated (1) that this composite-stimulus control was behaviorally reversible within subjects and, (2) within a single experiment, that the outcomes of the stimulus recombination tests were comparable after initial training under these different composite-training arrangements. The effect of prior conditioning was only revealed by the greater number of training sessions required to meet the discrimination training stability criteria during reversal (Phase 2) compared to original (Phase 1) training. This experiment also showed for the first time that a comparable number of training sessions was required to reach the 10:1 discrimination criterion in Phase 1 whether S^{Δ} was $\overline{T}+\overline{L}$ or T+L.

Reversing weakly established stimulus control would have been trivial. Therefore, we went to great lengths to establish strong and stable composite-stimulus control in Phase 1 before determining the extent it could be reversed in Phase 2. To achieve this, Phase 1 discrimination training continued for at least 16 sessions and until response rates in S^{D} components were at least 10 times those in the S^{Δ} component for three consecutive sessions. Then, the latter criteria were satisfied again before the second Phase 1 test was administered just prior to reversing stimulus control in Phase 2. The same criteria were used for the recombination tests in Phase 2 where S^{Δ} was reversed from T+L to $\overline{T}+\overline{L}$, or vice-versa, for each rat.

Despite the well established Phase 1 stimulus control, we were able to fully reverse it. Evidence for the quality and stability of the stimulus control established in each phase can be seen in Table 3 when the percentage of responses emitted to the recombined composite in each test condition is compared over the first and second tests of each Phase. The similarity in these percentages is striking. Convincing evidence that composite-stimulus control was completely reversed is also provided in Table 3 by the fact that the summative effect controlled by the composite containing elements only discriminative for response increase was of similar magnitude across phases.

Weiss and Schindler (1985) demonstrated for free-operant avoidance (FOA) of shock, and Coulter and Weiss (1971) for conditioned suppression, that eliminating a stimulus' excitatory history by no longer presenting shock during that stimulus, and thereby returning its control over behavior to baseline levels, does not necessarily eliminate ''silent'' residual influence(s) of conditioning history. In both studies, a currently safe stimulus with a shock-related history did not inhibit avoidance responding (Weiss & Schindler) or conditioned suppression (Coulter & Weiss) on a summation (stimulus compounding) test, while a stimulus without a shock history that signaled safety reduced avoidance by 50% (Weiss & Schindler).

The Weiss and Schindler (1985) finding stimulated, in part, the current experiment which used a testing procedure that has proven to be sensitive to history effects (Weiss & Schindler, 1985; Coulter & Weiss, 1971). In the Phase 2 (post S^{Δ} reversal) test, the composite composed solely of elements currently occasioning response increase controlled two to three times as many responses as those containing one stimulus element discriminative for response increase and one element discriminative for response decrease. This effect was comparable to that observed in Phase 1 (before S^{Δ} reversal).

Of the variety of functional comparisons one could make between Weiss and Schindler (1985) and the current experiment, three differences deserve comment. First, in Weiss and Schindler responding was maintained by negative reinforcement (FOA) while in the current experiment it was maintained by positive reinforcement (food). Second, in the current experiment the novel test stimulus was always composed of elements occasioning response increase in baseline while Weiss and Schindler's novel test compound contained an element that occasioned rate increase and another that had no effect on rate in the preceding baseline. Third, Weiss and Schindler simply discontinued FOA training during their stimulus, while in the present study animals were trained on a second (opposite) S^{Δ} discrimination.

Systematically replicating the present experiment with FOA occurring in $\overline{T}$+L and T+$\overline{L}$, and S^{Δ} being T+L or $\overline{T}+\overline{L}$, may prove informative. Emurian and Weiss (1972) have already demonstrated additive summation of FOA during stimulus compounding. In their training, baseline responding was maintained in ''tone'' and in ''light'' by FOA contingencies, where responding postponed shock, while $\overline{T}+\overline{L}$ was shock-free. If reversibility of composite stimulus control in the proposed study is not as complete as that reported in the present study with food, it would suggest that the stimulus control of behavior maintained under the aversive conditions related to negative reinforcement is less amenable to complete reversal than stimulus control related to positive reinforcement.

Changes in the on/off state of the light appear to have been more salient than changes in the on/off state of the tone regardless of whether T+L or $\overline{T}+\overline{L}$ acted as the S^{Δ} composite. This is consistent with the biological constraint on learning known as selective associations where hedonically positive events (e.g., food) favor visual control, while hedonically negative events (e.g., shock) increase auditory control (Foree & LoLordo, 1973; Schindler & Weiss, 1982; Weiss, Panlilio, & Schindler, 1993). A higher intensity light or a louder tone might have counteracted this differential saliency.

That increased responding was found to the composite stimulus containing elements only associated with response increase suggests that additive summation could be due to the removal of inhibitory sources of stimulus control. According to the composite-stimulus control model, the intermediate response rates observed during the $\overline{T}$+L and T+$\overline{L}$ test components were the result of subjects sampling one stimulus element discriminative for response increase and one element discriminative for response decrease. Therefore, replacing a response-decreasing element with one controlling response increase should lead to a higher response rate, as the stimulus recombination tests confirm. The reader is referred to Tsai and Weiss (1977), Weiss (1971, Exp. 1) and Weiss and Schindler (1987) for additional experimental evidence confirming the composite-stimulus control model.

The composite-stimulus control model allows apparently unitary and distinct stimuli, like the ''tone'' and the ''light'' used here, to be viewed as points on a composite continuum beginning with the composite containing only elements controlling response cessation (i.e., zero elements occasioning responding), continuing through composites containing an increasing proportion of elements occasioning responding, and ending with the composite containing only elements that occasion responding. In the present experiment, when S^{Δ} was the zero-stimulus-on composite ($\overline{T}+\overline{L}$), maximum responding occurred not to the training S^{D}s (the one-stimulus-on composites) but to the two-stimuli-on composite (T+L), the point on the continuum removed from the S^{D}s in a direction away from S^{Δ} (the zero-elements-on composite). Symmetrical outcomes were produced when the S^{Δ} was T+L.

Weiss (1969) recognized that this functional description of additive summation during stimulus compounding using the composite continuum was analogous to the definition of stimulus generalization peak shift. In peak shift experiments (e.g., Hanson, 1959) wherein S^{D} and S^{Δ} stimuli are from the same dimension (e.g., wavelength), on generalization tests maximum responding occurs not to the training S^{D}, but to a stimulus removed from that S^{D} in a direction away from S^{Δ}. On the basis of this functional equivalence, we might predict that the peak shift phenomenon is reversible (a prediction that, to our knowledge, has not been tested). More importantly, Weiss (1978) used the composite-stimulus-control model to successfully predict the results of stimulus compounding as well as generalization after intradimensional training according to his two-factor model of stimulus control (sketched below) in well over 100 experiments (See Tables 2 and 4 in Weiss, 1978). The identification of such converging operations (Sidman, 1960) is an important means by which we ''simplify'' and thereby make more comprehensible the natural world around us.

Bickel and Etzel's (1985) quantal model of stimulus control is very similar to the composite-stimulus control model proposed by Weiss (1969, 1972b). According to the quantal model, stimulus control is binary, i.e., a controlling stimulus-response relation is either activated or not. When activated, the response occurs; when not activated, the response does not occur. Intermediate rates of behavior are a function of the operation of two or more controlling stimulus-response relations (e.g., one unit controls responding and another unit controls the cessation of responding or some other behavior). Evidence supporting Bickel and Etzel's model comes from stimulus generalization and stimulus compounding studies where a microanalysis of response patterns revealed that no new behavior (e.g., different topographies or rates) was emitted in the presence of new stimuli or stimulus composites. Instead, apparently new behaviors were a function of different proportions of two or more previously established stimulus-response relations (e.g., Bushnell & Weiss, 1978; Weiss, 1972a).

The composite and quantal models could be two sides of the same coin. The composite model has shown how combinations of the on- and off-states of unitary, interdimensional stimuli can be conceptualized as forming a single, continuous dimension. The quantal model analyzes stimulus control that may appear to be a continuous and unidimensional process into discrete and unitary stimulus-response units. The models are similar in most other important aspects (e.g., assuming that stimulus control is an all-or-nothing process), when focusing only on stimulus-response relations. However, Weiss (1978) expanded the composite-stimulus analysis to incorporate, in addition to stimulus-response relations, the incentive-motive properties conditioned to stimulus elements through the implicit stimulus-reinforcer associations embedded within discriminative operant baselines.

This can be seen in the present experiment. When $\overline{T}+\overline{L}$ was associated with extinction while $T+\overline{L}$ and $\overline{T}+L$ both occasioned an increase in response rate, these tone and light stimuli also became associated with the resulting food reinforcement that would activate an incentive-motive process. Weiss' (1978) two-factor model of stimulus control describes how these response and incentive properties established to each composite element algebraically combine to produce behavior. This model is beyond the scope of the present article, but it has proven to have considerable explanatory power. For example, it permitted Weiss (1978, p. 369) to show how the composite-stimulus analysis explained (1) the comparable baseline response rates in $T+\overline{L}$ and $\overline{T}+L$ over three groups of rats trained on different three-component baselines, as well as (2) the results of subsequent composite-element recombination tests wherein T+L tripled rate in one group, doubled rate in another, and produced no rate change in the third. There is also evidence that the algebraic combination of conflicting discriminative response and incentive processes established to an S^D that occasions responding eliminates additive summation in the stimulus-compounding paradigm (Weiss & Van Ost, 1974) as well as peak shift in generalization experiments (Weiss & Dacany, 1982).

To conclude, by dimensionalizing what has traditionally been viewed as control by unitary orthogonal stimuli we have reduced the number of ''different'' behavioral phenomena requiring unique explanations. The parsimony resulting from such simplifying integrations is an important goal of the scientific enterprise.

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