COMPOUNDING DISCRIMINATIVE STIMULI CONTROLLING FREE-OPERANT AVOIDANCE¹

HENRY H. EMURIAN AND STANLEY J. WEISS

THE AMERICAN UNIVERSITY

The performances of three rats were stabilized on a multiple schedule that maintained responding by a free-operant avoidance schedule during independent presentations of tone and light. The simultaneous absence of these stimuli signalled shock-free periods and controlled response cessation. Subsequently, test sessions were administered consisting of independent presentations of each stimulus and these stimuli compounded (tone-plus-light). During an extinction test, additive summation was observed to the compounded stimuli, *i.e.*, more responses were emitted to the compound than to either tone or light. During a series of 28 maintenance-test sessions in which the shock schedule remained operative, the compounded stimuli produced a generally enhanced response rate and fewer pauses terminating with shock than either single stimulus condition. These results extend the generality of free-operant additive summation to responding maintained by aversive control. In addition, a comparison of the present study with previous experiments reporting additive summation of positively reinforced responding indicates that similar variables—rate and aversive differences between training stimulus conditions—should be considered in accounting for response distributions during stimulus compounding when responding is controlled by either positive or negative contingencies.

Additive summation of free-operant responding is observed when compound presentations of independently conditioned discriminative stimuli produce a greater response rate than either stimulus presented separately. Additive summation has been demonstrated during extinction compounding tests when responding during the independently conditioned stimuli was maintained in training by variable-interval (VI) schedules (Cornell and Strub, 1965; Weiss, 1964, 1969, 1971 Experiment 2; Wolf, 1963 Experiment 1) or by differential-reinforcement-of-low-rate (DRL) schedules (Weiss, 1968), and during compounding tests where reinforcement was continued when responding during the independent stimuli was maintained in training by VI (Meltzer and Freeman, 1971; Wolf, 1963 Experiment 2) and

by fixed-interval schedules (Miller and Ackley, 1970).

Whereas the consistency of these results established free-operant additive summation as a reliable behavioral phenomenon, the exclusive use of positive reinforcement schedules to maintain responding restricts its generality. Although Miller (1969) and Reiss (1969) demonstrated enhancement to compounded stimuli of responding maintained by aversive control, the independently conditioned stimuli did not explicitly control free-operant responding. The present experiment investigated the effects of stimulus compounding when stimuli independently controlling free-operant avoidance are compounded during extinction and response maintenance.

METHOD

Subjects

Three naive male hooded rats, approximately 275 g at the commencement of training, were maintained with free access to food and water in their home cages.

Apparatus

The operant training chamber measured 8 in. high, 8.25 in. long, and 7 in. wide (20 by 21 by 17.5 cm). The front and rear chamber

¹This experiment was based on a thesis submitted to the department of Psychology, The American University, in partial fulfillment of the requirements for the M. A. degree. It was supported by Grant MH-16853 to the second author from the National Institute of Mental Health, United States Public Health Service. An earlier version of this paper was presented at the 1970 American Psychological Association Convention in Miami. The authors thank Maureen Christian, Larry Cohen, and Susan Levine for their assistance. Reprints may be obtained from Henry H. Emurian, The American University, Department of Psychology, Washington, D. C. 20016.

walls were constructed of aluminum, and the side walls and ceiling were 0.25 in. (0.6 cm) white translucent plastic; the ceiling was vented with 0.25-in. (0.6-cm) diameter holes. The chamber floor was composed of 0.125 in. (0.3 cm) diameter stainless steel rods spaced apart 0.5 in. (1.3 cm) between centers. A Gerbrands microswitch lever was located on the right side of the front wall, 2.75 in. (6.9 cm) above the floor. A feeder trough, which was inoperative throughout the experiment, was mounted on the left side of the front wall at floor level.

A 2000-Hz tone stimulus employed in training and testing was generated by a BRS AA-201 audio oscillator, amplified by a BRS AO-201 amplifier, and presented through an 8-in. (20-cm) speaker mounted within an enclosure centered 8.25 in. (20.6 cm) above the training chamber. The tone intensity was approximately 90 dB measured at the lever with a Type 1565-A General Radio Sound Level Meter, scale C. With the exhaust fan operating, the ambient noise level was approximately 80 dB, and the tone stimulus was practically inaudible outside the attenuation chest.

The light stimulus employed in training and testing was generated by two 6-in. (15-cm) 25-w, 120-v bulbs, each horizontally mounted 4 in. (10 cm) from the translucent side walls. Each bulb was enclosed in a ventilated clear plastic cylinder to augment heat dissipation. These two bulbs together produced approximately 130.2 cd/m² measured with a Honeywell Pentax 1°/21° Photometer that was positioned 5 in. (12.5 cm) from the chamber's side wall.

A shielded 7-w, 120-v bulb operating at 3 w served as a houselight that was on continuously. The illumination it produced was too dim to activate the photometer, but it nonetheless allowed the experimenter to view the subject within the apparatus. The training chamber and its associated stimulus presentation devices were enclosed within a sound attenuation chest described elsewhere (Weiss, 1970). Solid-state scheduling equipment was located in a room adjacent to that housing the training chamber. Constant current shock was generated by a Lehigh Valley Electronics 1531 shocker and delivered to the grid floor, manipulandum, and front and rear walls through its associated scrambler.

Procedure

Baseline training. The performance of each subject was stabilized on a multiple (*mult*) free-operant avoidance extinction (EXT) schedule. A free-operant avoidance schedule (Sidman, 1953) was operative during independent presentations of 3 to 3.5 min tone and light stimuli. On this schedule, each lever press postponed a shock for a constant period of time, the response-shock (RS) interval. In the absence of responding, the time between shocks was determined by a shock-shock (SS) interval. The RS interval was in effect at each stimulus onset. The avoidance stimuli were separated by shock-free intervals signalled by light-out no-tone, $\overline{T} + \overline{L}$. These shock-free periods varied from 3 to 5 min within sessions and were followed immediately by a tone or light stimulus. Tone and light stimuli were presented in a nonsystematic order with the limitation that no more than three identical avoidance stimuli be presented in succession. Training sessions lasted from 4 to 5 hr.

The lever was wired into the shock-duration timing circuit to discourage the subject from holding it down continuously. Responding during a shock reset the shock-duration timer, thereby prolonging the shock for the time equal to the fixed shock duration. Response-shock and SS intervals, as well as shock intensity and duration, were adjusted across training sessions to terminal values that yielded stable avoidance and stimulus control for each subject. Shock intensity and duration for Subjects 6, 8, and 10 were respectively: 0.8 mA, 0.5 sec; 2.2 mA, 0.5 sec; and 1.5 mA, 0.5 sec. The RS interval was 20 sec for all subjects, while the SS interval was 5 sec for Subjects 6 and 10, and 2 sec for Subject 8.

Baseline training sessions continued until a subject satisfied a steady-state performance criterion for five successive sessions of constant shock and schedule parameters. The criterion required (1) avoidance of at least 80% of the first shocks scheduled at each avoidance stimulus onset, tone or light, and (2) abrupt and sustained response cessation during the shock-free $\overline{T} + \overline{L}$ periods separating these stimuli. Subject 6 required 36 sessions to reach the criterion; Subjects 8 and 10 required 24 and 23 sessions, respectively.

Extinction stimulus-compounding test. After a 1-hr warmup on the training multiple sched-

ule, a compounding test was administered with the shock disconnected. One-minute tone, light, and tone-plus-light periods were presented in each of 16 block replications. These stimuli, presented in nonsystematic order over replications, were each separated by 3-min $\bar{T}+\bar{L}$ interstimulus intervals. Subject 6 received all test replications in succession while Subjects 8 and 10 received 15 to 20 min of the training multiple schedule, with the shock reinstated, between each four blocks of replications.

Maintenance stimulus-compounding tests. After the extinction compounding test, the subject received five consecutive sessions on its training multiple schedule. It was subse-

quently tested with the free-operant avoidance schedule operative throughout all tone, light, and tone-plus-light stimulus presentations over the following 28 sessions. Each session began with a 30-min warmup on the training multiple schedule followed by 3-min tone, light, and tone-plus-light stimuli presented once in each of five replications. These stimuli were separated by 3-min shock-free interstimulus intervals signalled by $\bar{T}+\bar{L}$.

RESULTS

Training performance. The cumulative records of each subject, presented in Figure 1, graphically illustrate the stimulus control con-

Fig. 1. Cumulative records of each subject from one of the last five training sessions. T and L denote tone and light stimuli delimited by the up position of the response pen. Each of these stimuli signalled a free-operant avoidance schedule. Light-out no-tone periods, during which the free-operant avoidance schedule was not in effect, are indicated by depression of the response pen. Oblique marks by the response pen indicate shocks.

ditioned by the training schedule. Responding prompted by the first scheduled shock occurred on fewer than 20% of stimulus presentations and essentially ceased during $\overline{T+L}$ periods.

Table 1

Means and standard deviations of responses and shocks per minute computed from the last five baseline training sessions.

Subject		Stimulus Conditions*					
		Responses Per Minute			Shocks Per Minute		
		T	L	$\overline{T+L}$	T	L	
6	Mean	12.4	13.3	1.1	0.5	0.5	
	SD	1.0	1.6	0.7	0.3	0.2	
8	Mean	5.0	4.9	0.2	1.5	1.4	
	SD	0.3	0.4	0.0	0.2	0.1	
10	Mean	8.6	8.5	0.6	0.5	0.5	
	SD	0.8	0.5	0.2	0.2	0.0	

* T = tone, L = light, $\overline{T+L}$ = light-out no-tone.

The data presented in Table 1 indicate that the mean responses and shocks per minute during tone and light were essentially equivalent for each subject over the five criterion training sessions. The relatively high shock frequency apparent in the terminal data of Subject 8 suggests that the performance of this

Table 2

Total Stimulus-Compounding Test Responses

Subject	Replications	Stimulus Conditions*			
		T+L	T	L	$\overline{T+L}$
6	1-4	97	41	46	0
	5-8	52	30	6	0
	9-12	35	15	3	0
	13-16	35	7	3	0
	Total	219	93	58	0
8	1-4	7	3	2	0
	5-8	7	4	3	0
	9-12	7	3	0	0.3
	13-16	7	5	3	0
	Total	28	15	8	0.3
10	1-4	19	14	8	0.7
	5-8	22	4	5	0.7
	9-12	21	8	4	0.3
	13-16	28	8	5	0
	Total	90	34	22	1.7

* T+L = tone-plus-light, T = tone, L = light, $\overline{T+L}$ = light-out no-tone. T+L represents the mean of the three 1-min pre-stimulus periods for each replication totaled within test quarters.

animal was controlled by shocks to a greater extent than for Subjects 6 and 10.

Extinction test. Table 2 presents total response outputs of each subject during tone, light, and tone-plus-light within successive

Fig. 2. Cumulative records of each subject for maintenance-test sessions one through four and each fourth session thereafter. Successive ordinal positions of the five 3-min test-stimulus conditions represent the replications in which the stimulus was presented during respective test sessions. T+L = tone-plus-light, T = tone, L = light. A free-operant avoidance schedule was operative during T+L, T, and L. Oblique marks by the response pen indicate shocks.

blocks of four test replications. All subjects exhibited enhanced free-operant avoidance during the compounded stimuli throughout the test: more responses were emitted during tone-plus-light than during tone or light. For Subjects 6 and 10, rate of responding declined more rapidly during the independent stimuli, causing the relative proportion of total responses emitted during the compounded stimuli to increase as a function of successive replications.

Maintenance tests. Figure 2 presents for each subject cumulative records of each test stimulus for Sessions 1 through 4 and each fourth session thereafter. These records reveal graphically the tendency of the compounded stimuli to control a response rate higher than either single stimulus condition throughout a large proportion of the replications presented. A striking consistency noted in the performance of all subjects is the lower shock frequency during the compounded relative to the independent stimuli throughout the test sessions.

Figure 3 presents for each subject mean responses per minute and total shocks received during each test stimulus over successive sessions. Subjects 6, 8, and 10 maintained an enhanced response rate to compounded as compared to independent stimuli for 64.3%, 60.7%, and 96.4% of the sessions, respectively. For Subject 6, the compounded stimuli maintained enhanced rate throughout the first nine consecutive sessions, after which rate overlapped with that maintained by the independent stimuli. For Subject 8, enhanced rate was most evident during the latter half of the sessions. Subject 10 exhibited enhanced rate during the compounded stimuli throughout almost all maintenance-test sessions. Responding during $\overline{T}+\overline{L}$ was negligible for all subjects over sessions.

Figure 3 also indicates that the number of shocks received by each subject during the compounded stimuli was consistently less than those received during single stimulus conditions throughout successive sessions, even when response rate was higher during the independent stimuli. This suggests that (1) the higher response rate occasionally observed during tone or light was to some degree a function of the greater number of shocks and consequent post-shock response bursts inflating rate during these stimuli, and (2) the com-

pounded stimuli maintained more efficiently spaced responding, defined in terms of effectiveness in avoiding shock, than either tone or light.

DISCUSSION

The present experiment investigated the effects of compounding stimuli that independently controlled free-operant avoidance responding. When the stimuli were compounded during an extinction test, a greater response rate was observed during the compounded stimuli than during either single stimulus condition. These response-enhancement effects are similar to free-operant additive summation observed when stimuli independently controlling positively reinforced responding were compounded, and thereby extend the generality of free-operant additive summation to responding maintained by aversive control.

When the independently conditioned stimuli were compounded during response maintenance, the compounded stimuli produced enhanced response rates for a majority of the test sessions for two subjects, and enhanced responding during 27 of the 28 sessions for the third subject. For all subjects, fewer shocks were received during the compounded stimuli than during either single stimulus condition throughout the maintenance-test sessions. Examination of maintenance-test cumulative records indicates that the high frequency of shocks occurring during tone or light often inflated the response rate during those stimuli, thereby reducing the disparity in rate between the compounded and independently conditioned stimuli. This suggests that the summative effect during compounded stimuli may have been partially masked by the shock-inflated rates during the independent presentations of the stimuli composing it.

Wolf (1963 Experiment 2) reported that enhanced responding during compounded stimuli independently controlling responding maintained by VI schedules progressively abated as a function of exposure throughout three successive maintenance-test sessions during which the 4-min compound was presented 36 times. With similar training schedules, Meltzer and Freeman (1971) reported enhanced responding to compounded stimuli over sixty 1-min extinction probe tests. In the present experiment, the compounded stimuli

Fig. 3. Mean responses per minute and total shocks received by each subject during each test stimulus within successive maintenance-test sessions. Legends are presented in the data frames of Subject 6.

more effectively sustained control of rates effective in avoiding shock than either tone or light despite 320 min of contact with the compound during response maintenance. This suggests that summative effects might be better sustained by stimuli associated with aversive than positive contingencies.

Previous investigations reporting free-operant additive summation employed multiple schedules during training in which responding was maintained during the independently conditioned stimuli by schedules of positive reinforcement. With one exception (see Weiss, 1971 Experiment 2) these studies employed extinction to control response cessation during the simultaneous absence of the stimuli maintaining responding. Within the context of stimuli signalling positive reinforcement schedules, an extinction component, or timeout from positive reinforcement, acquires aversive characteristics (Azrin and Holz, 1966). Thus, additive summation has been previously demonstrated after training in which the stimulus condition controlling response cessation was relatively more aversive than the stimulus conditions maintaining responding.

In the present experiment, the stimuli maintaining responding signalled a free-operant avoidance schedule, while their simultaneous absence signalled a period free from shock: a timeout from avoidance. Several experiments have demonstrated that a timeout from avoidance acquires characteristics of a positive conditioned reinforcer (LoLordo, 1969; Verhave, 1962), thereby indicating that this stimulus condition in the present study was relatively less aversive than the stimuli maintaining responding. Therefore, the aversive relations between those independently conditioned stimuli maintaining responding and their simultaneous absence are reversed in the studies reporting free-operant additive summation where positive reinforcement maintained responding, and the present study where responding was maintained by an avoidance schedule.

This comparison suggests that the absolute aversive characteristics of the schedules maintaining responding during training is not a limiting condition in the production of free-operant additive summation. Additive summation occurs with compounded stimuli that are both relatively less aversive than their simultaneous absence, or relatively more aversive, depending upon the incentive controlling

responding—positive or negative reinforcement respectively.

According to the analysis presented by Weiss and Emurian (1970), the rate difference between the stimuli maintaining responding and their simultaneous absence controlling response cessation was a necessary condition for the summative effects observed in the present experiment. However, they also stated that the reinforcement densities during these stimuli "... might interact with these rates to determine the distribution of responses during a stimulus compounding test" (p. 209). This interaction was supported by Weiss (1971, Experiment 2) who reported substantially weaker additive summation when positive reinforcement was associated with response cessation, as well as the VI schedules maintaining responding than when response cessation was controlled by extinction. Although this rate-reinforcement difference interaction was not investigated in the present study, the comparison between stimulus compounding studies employing positive reinforcement to maintain responding and the present experiment that employed an avoidance schedule clearly indicates that a disparity in aversive characteristics between stimulus conditions existed within both classes of experiments. (We are using the organism's preference, inferred from past research cited above, to conceptualize aversive relations between schedules effective during the stimuli maintaining responding and those controlling response cessation in both incentive situations.) Therefore, it appears that similar variables deserve attention when predicting response distributions during stimulus compounding when responding is controlled by either positive or negative contingencies.

REFERENCES

- Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig, (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 380-447.
- Cornell, J. M. and Strub, H. A. A technique for demonstrating the inhibitory function of S-. *Psychonomic Science*, 1965 3, 25-26.
- LoLordo, V. M. Positive conditioned reinforcement from aversive situations. *Psychological Bulletin*, 1969, 72, 193-203.
- Meltzer, D. and Freeman, B. J. Maintenance of response summation under conditions of minimum stimulus intensity. *Psychonomic Science*, 1971 22, 287-289.

- Miller, L. Stimulus compounding with an instrumental avoidance response. *Psychonomic Science*, 1969, 16, 46-47.
- Miller, L. and Ackley, R. Summation of responding maintained by fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 199-203.
- Reiss, D. Pavlovian phenomena in conditioned acceleration—stimulus summation. *Conditional Reflex*, 1969, 4, 257-264.
- Sidman, M. Avoidance conditioning with brief shock and no exteroceptive stimulus. *Science*, 1953, 118, 157-158.
- Verhave, T. The functional properties of a timeout from an avoidance schedule. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 391-422.
- 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. *Free-operant compounding of low-rate stimuli*. Paper presented at the 1968 convention of the American Psychological Association, San Francisco, California.
- Weiss, S. J. Attentional processes along a composite stimulus continuum. *Journal of Experimental Psychology*, 1969, 82, 22-27.
- Weiss, S. J. An effective and economical sound attenuation chamber. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 37-39.
- Weiss, S. J. Free-operant summation and discrimination training: consideration of non-reinforcement and response-differentiation consequences of S^A. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 387-402.
- Weiss, S. J. and Emurian, H. H. Stimulus control during the summation of conditioned suppression. *Journal of Experimental Psychology*, 1970, 85, 204-209.
- Wolf, M. M. Some effects of combined S^ps. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 343-347.

Received 26 February 1971.

(Final acceptance 8 November 1971.)