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FREE-OPERANT COMPOUNDING OF VARIABLE-INTERVAL AND LOW-RATE DISCRIMINATIVE STIMULI[1]

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Four rats were trained on a schedule containing stimuli associated with variable-interval 30-sec and differential-reinforcement-of-low-rate 20-sec schedules of reinforcement. Subsequently, a stimulus compounding test was administered that included individual presentations of two intensities of each stimulus plus compounds of these stimuli. In training, extremely high rates were emitted to the variable-interval stimulus, and very low rates to the differential-reinforcement-of-low-rate stimulus. Compounding the two training stimuli always produced an overall response rate intermediate between the rates controlled by the two stimuli separately presented. Essentially the same relationship held with different stimulus intensities. These results resolve the confounding of response and reinforcement variables present in previous conditioning studies reporting response averaging. They are discussed in terms of the incompatibility of the response chains associated with the individual stimuli compounded.

Stimulus compounding has been studied by simultaneously presenting two or more stimuli that had previously been conditioned singly. Additive summation is observed when a greater response is produced to the compound stimulus than to any of the component stimuli presented separately. Response averaging occurs when the response rate, or magnitude, to the compound is intermediate between the rates controlled by the individual stimuli. These phenomena have been recorded in both classical and instrumental conditioning.

When stimulus compounding produced additive summation, the separately conditioned stimuli had each been previously associated with reinforcement and maintained roughly similar, if not identical, response rates or magnitudes [Leporsky (in Pavlov, 1927, p. 79), Weiss, 1964, Wolf, 1963]. To yield response averaging though, one of the stimuli compounded was reinforcement-associated and maintained responding, while the other signaled extinction, *i.e.*, the absence of reinforcement, and produced a negligible response [Leporsky (in Pavlov, 1927, p. 79), Cornell and Strub, 1965]. Therefore, either the absence of reinforcement in one of the stimuli, or the concomitant low response rate, could be responsible for response averaging observed in these studies. Response and reinforcement variables are confounded in the comparison of additive summation and response averaging paradigms.

To isolate the reinforcement and rate factors, Variable-interval (VI) and differential-reinforcement-of-low-rate (DRL) stimulus-associated contingencies were chosen to produce widely divergent rates while reinforcing responses to both stimuli subsequently compounded. On the response rate continuum, conditions were similar to those that previously produced response averaging. However, by having both stimuli independently associated with reinforcement, the procedure was similar to those that led to additive summation.

METHOD

Subjects

Four naive adult male hooded rats, approximately 400 g at the start of deprivation, were trained and tested at 80% of this weight.

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Apparatus

A light-tight, ventilated, sound-insulated operant chamber was constructed of 0.5-in. plywood, with Armstrong Arrestone sound insulating material on its four interior walls and ceiling. These perforated metal interior insulating walls were separated from the exterior plywood walls by 1.5 in. of mineral woolpad. The animal stood on a 0.5-in. hardware cloth floor above San-i-cell bedding. The interior dimensions measured 8.75-in. high, 7 in. long, and 5 in. wide, so that the subject was always close to the stimulus sources.

A 1.5-in. by 3/8-in. microswitch bar that protruded 3/8 in. was located on the front wall of the chamber, and a small food trough was to the left of, and below, the bar. Sound stimulation was presented by a 5-in. 4-ohm Jensen speaker mounted on the middle of the outside rear wall before a 3-in.-square opening in the plywood. The 1500-cps 94.8-db tone employed in training was generated by a Hewlett-Packard Audio Oscillator Model 200 AB. This sound level measurement was taken with a Type 1551-C General Radio Sound Level Meter, Scale C, with the microphone located directly above the bar of the closed training chamber. The ambient noise level, with only the exhaust fan running, was 56.8 db.

Light stimulation was produced by a G.E. 209 bulb enclosed in a small metal box placed over a 1⅝-in. square hole cut through the ceiling of the chamber. A neutral density filter could be inserted directly below the bulb without disturbing the apparatus. Half of a white ping-pong ball served as a hemispherical light diffuser over the hole in the ceiling. The training light intensity was 12.0 foot candles measured with a Honeywell Pentax 1°/21° Photometer 4-in. from the diffuser in a dark room. A 1° acceptance angle was used to read the incident light off the hemisphere.

Standard relay apparatus was located in a room across the hall from that housing the training chamber. Reinforcers were Noyes 45-mg rat pellets.

Procedure

After magazine training and shaping, the terminal training contingency was gradually approximated. This was a chained schedule in which withholding bar response during S_2 produced, on a randomized basis, either a VI 30-sec or a DRL 20-sec S_1 reinforcement period. The S_2, whose no-response requirement varied within the limits of 20 and 60 sec between sessions, was reinstated at the termination of each 3-min S_1. During the VI stimulus component, a reinforcement was delivered for the first response after an average of 30 sec had elapsed since the previous reinforcement. The limits of this schedule were 2 and 80 sec. During the DRL stimulus component, a response was reinforced only if the interresponse time was at least 20 sec. Rats 51 and 52 had the VI component associated with the tone, and the DRL with the light; these schedule-stimulus combinations were reversed for Rats 53 and 54. A blackout, no-tone condition was correlated with S_2. The subjects were trained on this schedule for 35 sessions, each of which lasted approximately 2.5-hr or 120 pellets, whichever occurred first.

A stimulus compounding test followed the training phase. This test contained a training (TRN) and generalization (GEN) stimulus from each modality presented singly and in combinations of two to a subject. A 1500-cps 86.8-db tone and a 0.6 foot-candle light served as generalization stimuli. The test conditions were: (VI 30_{TRN} + DRL 20_{TRN}); (VI 30_{TRN} + DRL 20_{GEN}); (VI 30_{GEN} + DRL 20_{TRN}); (VI 30_{GEN} + DRL 20_{GEN}); VI 30_{TRN}; VI 30_{GEN}; DRL 20_{TRN}; and DRL 20_{GEN}. Characterizing these conditions by the numbers 1 through 8 successively, the orders of presentation of the four replications were 83547162, 62175384, 13854726, and 76423581. This order over test replications attempted to balance the reduction of responding during extinction over the test conditions in successive replications. Each stimulus presentation lasted 45 sec per replication with a 30-sec stimulus-off period separating presentations. The compounding test, which was performed during extinction, began after 60 reinforcements of the training schedule.

RESULTS

The representative cumulative records of Fig. 1, from the final day of training, show the degree of stimulus control for each subject. Differential rates during the VI 30-sec and DRL 20-sec S_1 reinforcement periods are consistently evident; responding usually

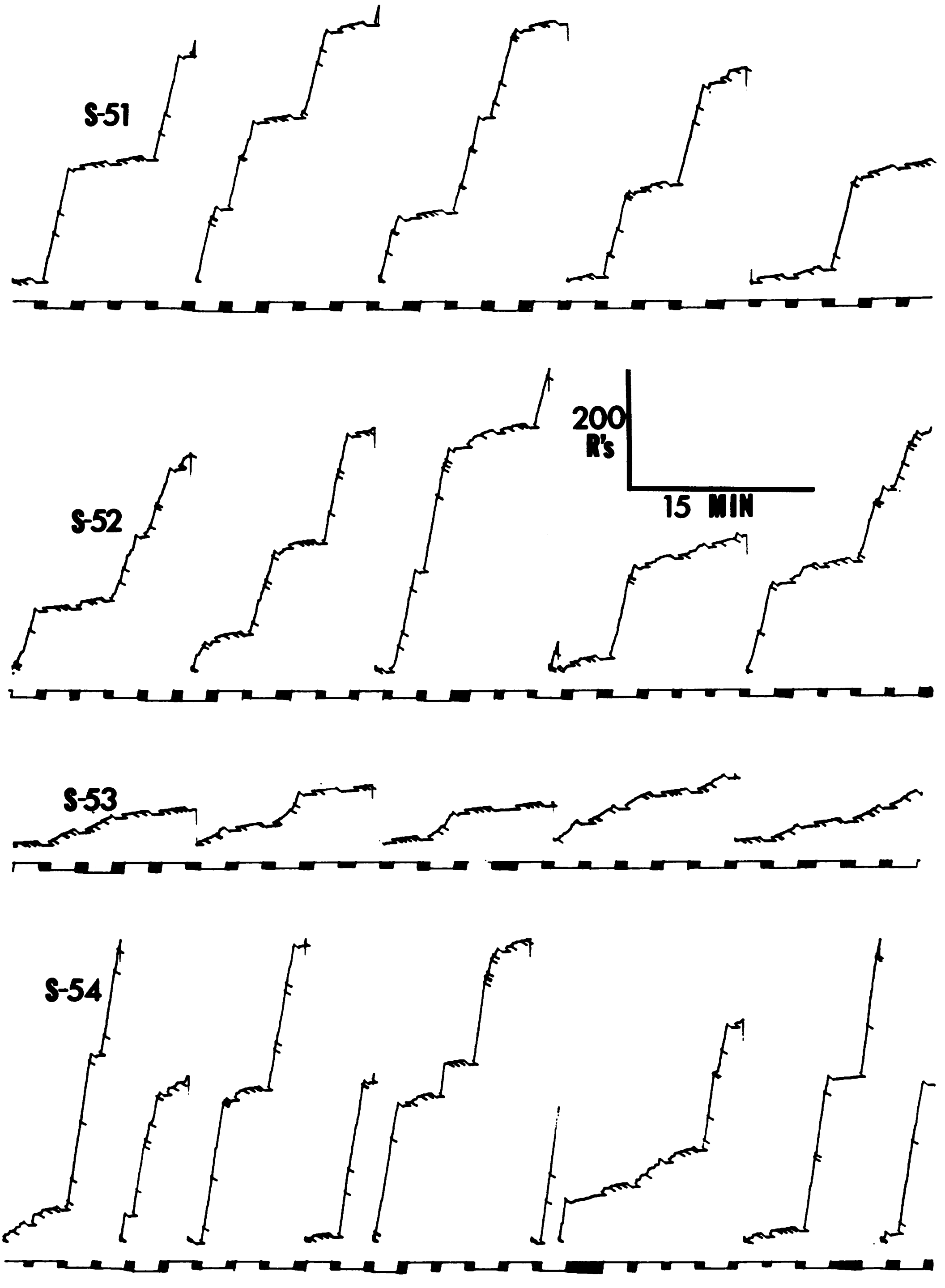

Fig. 1. Cumulative records of the four subjects during their final training session. The VI 30-sec contingency is effective when the base line is in the lower register, the DRL 20-sec when it is elevated. The solid portions of the base line and depression of the cumulative response pen identify the S_2 blackout, no-tone periods. Slash marks by this pen, which reset after 500 responses and every 15 min, record reinforcements. For Rats 51 and 52 a tone was paired with the VI schedule, a light with the DRL; the opposite stimulus-schedule combinations were employed for Rats 53 and 54.

ceased abruptly at the termination of the S_1 periods; and rate at the onset of an S_1 was appropriate to the reinforcement contingency associated with that stimulus. These rates indicate that the rats were not probing the reinforcement characteristics of the respective VI and DRL components before stabilizing at a uniform rate for a particular period. For each stimulus-schedule, combination control by the respective S^Ds, and not other characteristics of the training schedule, is apparent. Nevertheless, the record for Rat 53 appears distinctly different from Rats 51, 52, and 54. Rat 53's rate difference between the VI and DRL S^Ds in training was in the order of 7.9 to 1. Rats 51, 52, and 54, in comparison, showed more extreme rate differences to their VI and DRL S^Ds, the average ratio being 18.2 to 1.

Figure 2, presenting mean response percentages averaged over all subjects for each of the test conditions, indicates that the proportion of responses emitted to compound stimulus presentations was between the higher percentage to the VI S^D and the lower percentage to the DRL S^D constituting the compound stimulus. (A response percentage for a test condition was calculated by dividing an animal's response output to that condition by the total number of responses it emitted to all eight test conditions.) For example, an average of 22.2 per cent of an animal's responses were emitted to the VI 30_{TRN} S^D, while 15.9 per cent were emitted to the simultaneous presentation of the VI 30_{TRN} and DRL_{TRN} S^Ds, and only 2.4 percent were made in the presence of the DRL_{TRN} S^D presented alone. This ordering among the rates emitted to any compound and its components in Fig. 2 was essentially consistent across animals.

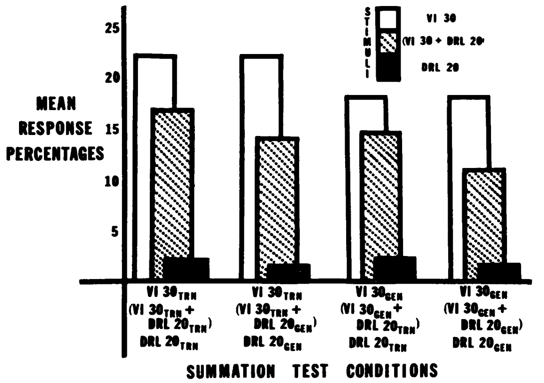

Fig. 2. The proportion of responses emitted to each stimulus condition of the compounding test. Each bar represents the mean of four subjects. VI 30-sec and DRL 20-sec conditions specify the individual presentation of stimuli associated with the respective schedules for each subject; (VI 30 + DRL 20) represents the simultaneous presentation of these stimuli. Subscript TRN refers to the training stimulus for the respective schedule; subscript GEN refers to a stimulus along the intensity generalization gradient of the training stimulus.

Table 1 presents the data from Fig. 2 for individual subjects. Note the number of responses emitted to the compound presentation of S^Ds (VI 30 + DRL 20), and its VI 30-sec and DRL 20-sec S^D components across rows. In 13 of the 16 compound stimulus presentations, the number of responses emitted in the presence of a compound condition was intermediate between the number emitted to each of the stimulus elements composing the compound. This relationship is consistently evident when training stimuli are compounded. The only exceptions to response averaging to compound presentations occurred occasionally when generalized stimuli were employed with Rats 53 and 54.

Table I

Summation test responses emitted to each condition by individual subjects.

Condition	*Animal*	*VI 30*	*VI 30 + DRL 20*	*DRL 20*
VI 30_{TRN}	51	99	87	17
	52	78	35	8
DRL 20_{TRN}	53	52	38	4
	54	214	171	15
VI 30_{TRN}	51	99	36	15
	52	78	39	3
DRL 20_{GEN}	53	52	30	3
	54	214	232	10
VI 30_{GEN}	51	125	40	17
	52	82	69	8
DRL 20_{TRN}	53	23	50	4
	54	110	89	15
VI 30_{GEN}	51	125	25	15
	52	82	39	3
DRL 20_{GEN}	53	23	43	3
	54	110	88	10

Table 2, which divides the data of Table I into the responses emitted by each subject during the first and second halves of the test replications, shows that response averaging was produced to compound stimulus presentations consistently during replications 1 and

2 by Rats 51, 52, and 54. Only Rat 53, which exhibited the smallest difference between VI and DRL response rates in training, was inconsistent. It showed what looks like additive summation for its (VI 30_{GEN} + DRL 20_{TRN}) and (VI 30_{GEN} + DRL 20_{GEN}) test conditions. During replications 3 and 4, when response rates were in general appreciably lower, all animals except Rat 52 showed some evidence of additive summation.

Although valid comparisons can be made between the responses emitted to individually presented VI and DRL stimuli, and to these stimuli compounded, the generalization gradients show that the generalized tone and light stimuli were not equivalent across schedules. During test replications 1 and 2 (see Table 2) the tone dimension produced inverted VI gradients (Rats 51 and 52) and flat DRL gradients (Rats 53 and 54). Sloping VI and DRL gradients were noted along the light continuum for all subjects. On the latter half of the replications, the tone produced conventional sloping gradients for all animals; the light produced only one inversion. These generalization results could be due to a greater difference (in decibels) between training and generalized light than training and generalized tone, with the discrimination on the tone dimension improving over stimulus presentations. Total data of Table 1 indicate sloping gradients for the DRL schedule, regardless of modality; this is not true for the VI schedule.

DISCUSSION

This experiment demonstrated that a compound of two training stimuli, one associated with a VI schedule of reinforcement and the other with a DRL schedule, controls an overall response rate intermediate between the rates controlled by the two stimuli separately presented. In general, the same relationship held when generalized stimuli were presented. This finding is quite different from the additive summation consistently reported by Weiss (1964). The essential difference between the present study and Weiss' is the substitution of a DRL 20-sec for a VI 75-sec schedule. Although reinforcement frequency was similar in the presence of these schedule components during the training phase of both experiments, rates, relative to the VI 30-sec component, were not comparable. There was a more extreme rate difference between VI 30-sec and DRL 20-sec schedules in the training phase of this experiment than between the VI 30-sec and VI 75-sec schedules in the earlier one. Therefore, the different results in these two experiments could be due to schedule effects, VI *versus* DRL, or the relative differential response rates to the two training stimuli in

Table II
Summation test responses emitted during the initial and final halves of the test replications.

	Stimulus Intensity		*Extinction Replications*					
			1 & 2			*3 & 4*		
Animal	*VI*	*DRL*	*VI*	*VI + DRL*	*DRL*	*VI*	*VI DRL*	*DRL*
51	trn	trn	97	82	16	2	5	1
	trn	gen	97	35	11	2	1	4
	gen	trn	125	29	16	0	11	1
	gen	gen	125	25	11	0	0	4
52	trn	trn	62	27	6	16	8	2
	trn	gen	62	32	3	16	7	0
	gen	trn	80	68	6	2	1	2
	gen	gen	80	39	3	2	0	0
53	trn	trn	40	9	2	12	29	2
	trn	gen	40	18	2	12	12	1
	gen	trn	16	36	2	7	14	2
	gen	gen	16	34	2	7	9	1
54	trn	trn	196	155	9	18	16	6
	trn	gen	196	142	9	18	90	1
	gen	trn	105	75	9	5	14	6
	gen	gen	105	77	9	5	11	1

each experiment. *Nevertheless, one of the stimuli compounded does not have to be associated with extinction for response averaging to occur.*

Although all subjects were under control of the schedule-associated stimuli, the form of this control split the four subjects into two distinct classes. Response rates to the VI- and DRL-associated stimuli were extremely divergent for Rats 51, 52, and 54, while Rat 53 displayed a smaller rate difference. This subject (Rat 53) produced two of the three exceptions to the averaging otherwise noted to the compound stimulus presentations. Thus, a relationship could exist between the relative rates controlled by each of the stimuli compounded and the averaging to compound presentations essentially observed in this study. Behavior under the test conditions was therefore analyzed when rate differences to VI and DRL stimuli were great, early in testing, and when this difference decreased, later in testing.

On the first half of the test replications, the animals that displayed extreme rate differences to the two stimuli in training, 51, 52, and 54, without exception showed an intermediate response output to the compound presentations of training, training and generalized, and generalized stimuli. Rat 53, which did not show as extreme rate differences to the VI and DRL stimuli in training, failed to average to the compound stimuli composed in part of its VI 30-sec generalized stimulus, which controlled a relatively low rate during the test. Test replications 3 and 4 in Table 2 suggest how the relative response rates controlled by the single stimulus and compound test conditions were affected by a severe reduction in response rate, especially to the VI stimuli. With the exception of Rat 52, additive summation, rather than averaging, was demonstrated in at least half of the compound stimulus presentations of the second half of the extinction replications. Again, in the present experiment, rate averaging to compound stimulus presentations was at least partly related to the stimuli's individual control of extremely different rates.

The intermediate response to compound stimulus presentations when the rates controlled by the two stimuli are extremely different could be due to the incompatible responses occasioned by the two stimuli. Hearst, Koresko, and Poppen (1963) reported pausing and frequent stereotyped response chains to DRL contingencies. Reinforcement on the VI 30-sec schedule is unlikely to allow the development of chains of behavior which will compete with the response of pressing the bar. (See cumulative records of Rats 51, 52, and 54). Therefore, the VI and DRL stimuli together, when all responses are in substantial strength, can certainly provide an opportunity for behaviors conditioned in the presence of the DRL stimulus to occur in the presence of the compound stimulus and to interfere with bar pressing at the high rate previously controlled by the VI stimulus. The behavioral form of this conflict could be better analyzed if interresponse time (IRT) distributions had been recorded during the stimulus compounding test. Bimodal IRTs during compound stimulus presentations could indicate alternating attention between VI- and DRL-associated stimuli, or some intermediate distribution could indicate simultaneous attention to both stimuli. The cumulative records do not allow this fine an analysis.

Since long VI schedules seem to produce response rates and patterns similar to those of DRL (Hearst *et al.*, 1963), the averaging effect noted here to the simultaneous application of VI and DRL S^Ds could be expected by compounding stimuli, one associated with short, the other a long VI schedule. This demonstration would eliminate the confounding of class of reinforcement schedule and rate difference in the present experiment, and strengthen the conclusion that response averaging is due to an incompatibility of the response chains associated with the individual stimuli compounded.

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