# SOME EFFECTS OF COMBINED $S^Ds$[1]

MONTROSE M. WOLF[2]

ARIZONA STATE UNIVERSITY

When the individual $S^D$ components of a multiple schedule were combined, their control over a response summated, thus increasing the response probability to a point over that controlled by either of the $S^D$s independently. Summation was concluded to be a phenomenon relevant for operant as well as respondent stimulus control (Pavlov, in Kimble, 1960; Hull, 1943). The results of the present study appear to be a special case of the general $S^D$ enhancement effect demonstrated by Hanson (1959) and by Pierrel and Sherman (1960).

Pavlov (Kimble, 1960) and Hull (1940) both demonstrated that the effects of combined conditioned stimuli are additive. In each case two CSs were individually conditioned. When presented in combination the CSs controlled a greater magnitude of response than when either was presented individually.

In operant conditioning the technical term corresponding to CS is $S^D$. Both a CS and an $S^D$ are originally neutral stimuli but through conditioning come to control a response. The research reported here was concerned with the additive strengths of combined $S^D$s. Control over the response by the individual $S^D$s was established by using a multiple schedule with either two or three $S^D$ components alternating with an $S^\Delta$. The $S^D$ stimuli were either in the same or in different sensory modalities. At a later period, these stimuli were presented simultaneously and their combined control over the response was compared with their separate control. Comparisons were made under conditions of extinction as well as ongoing reinforcement.

## METHOD

### *Subjects*

Five Holtzman albino rats, each 1 yr old at the beginning of the experiments, were used. All except Animal #5 were male.

### *Apparatus*

Standard electrical operant conditioning apparatus was used. The reinforcers were Noyes 45 mg rat pellets.

The 8 by 8 by 9-in. box was enclosed in a light-proof, sound-resistant outer box. The three visual stimuli available were three pairs of lights on the same wall as the bar and the food cup. Each pair was arranged vertically, ½ in. apart, as close as the equipment permitted. The pair to the left is referred to as $L_1$, the middle $L_2$ and the pair on the right as $L_3$. The middle pair, $L_2$, was located a few inches higher than the others. Each pair consisted of two GE #1815, 12-16 volt lamps supplied with 6.3 volts AC, except in the case of Animal #5 where a pair of GE #313, 28 volt lamps were supplied with 24 volts AC through a 68 ohm resistor in series. Each lamp was covered by a milky plastic cover which protruded into the cage. Two 1½ in. speakers used for auditory stimulation were on opposite side walls. These were supplied with a relatively pure sine wave of 1000 cps. The sound pressure level, measured in the center of the chamber, was approximately 95 db. The visual stimuli were wired to blink slightly every second. The auditory stimulus blipped off for an instant every second. An exhaust fan provided air circulation and some masking noise.

A house light consisting of a 28 volt lamp supplied by 6.3 volts AC, was continuously

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[2]Now with the Department of Psychology, University of Washington, Seattle 5, Washington.

present, except in the case of Animal #2 in Experiment I.

A force of more than 10-15 g was required to depress the bar. A bar press opened a normally closed relay, producing an audible click in the box.

## PROCEDURE AND RESULTS

The criterion for differential $S^D$-$S^\Delta$ control was designated as a response ratio of $S^\Delta$ $S^D < .10$ (Dinsmoor, 1952; Pierrel, 1958; and Pierrel and Sherman, 1960).

The sessions were run for the most part on consecutive days, and were from 2 to 4 hr in length.

During an experiment the subject (*S*) was maintained at 85% of normal pre-experimental free-feeding weight. After each session an amount of food was made available to bring *S*'s weight to the 85% level.

The bar training procedure began by allowing *S* some time in the apparatus for adaptation. During this time, reinforcers were occasionally made available. *S* was then hand-shaped to press the bar. Approximately 20 reinforcers were delivered CRF before placing *S* on its particular schedule.

Responses during the test runs were counted automatically and then plotted cumulatively.

*Experiment I*

*The effects of combined $S^D$s observed in extinction.* Two stimuli, for example a light and a tone, were each initially made separate $S^D$s. After $S^D$-$S^\Delta$ stimulus control reached the predesignated response criterion, the two stimuli were presented in combination. The effects of the combined $S^D$s were compared with those of the individual $S^D$s under conditions of extinction.

Four *S*s were run under slightly varied conditions. The main differences in the procedures were: (1) different combinations of two of the three possible stimulus lights; (2) no house light used for *S* #1, thus $S^\Delta$ was total darkness; (3) a light and a tone were the individual stimuli for *S* #4.

The training given *S*s #1 and 4 is described in detail. The training of *S*s #2 and 3 was similar to that of #1 and is not presented. *S* #4's training is described completely since it deviated significantly from the others.

*Animal #1.* After receiving bar training *S* was placed on a four-ply multiple schedule consisting of:

| mult $S^D$VI 30″, | $S^\Delta$ ext, | $S^D$VI 30″, | $S^\Delta$ ext. |
|---|---|---|---|
| $L_2$ | *No L* (*dark*) | $L_3$ | *No L* (*dark*) |

Each leg of the multiple schedule lasted 5 min, the sessions 2 hr.

After five days the schedule was changed to:

| mult $S^D$VI 1′, | $S^\Delta$ ext, | $S^D$VI 1′, | $S^\Delta$ ext. |
|---|---|---|---|
| $L_2$ | *No L* | $L_3$ | *No L* |

The sessions were extended to 4 hr, the length of each leg remaining 5 min.

The discrimination criterion requiring a response ratio of $S^\Delta/S^D < .10$ was reached after a total of 12 training sessions.

The test session was run in extinction with the following six-ply schedule:

| mult $S^D$ ext, | $S^\Delta$ ext, | $S^D$ ext, | $S^\Delta$ ext, | $S^D$ ext, | $S^\Delta$ ext. |
|---|---|---|---|---|---|
| $L_2$ | *No L* | $L_3$ | *No L* | $L_2 + L_3$ | *No L* |

The testing procedure for *S* #1 was standard for all animals in Experiment I. Each leg of the test schedule lasted 1 min. There were 20 successive presentations of the multiple schedule. The order of appearance of the various $S^D$s was randomized within each complete presentation of the multiple schedule, with the limit that no $S^D$ could follow directly upon itself in the next presentation.

The responses emitted during the 1 min appearances of each $S^D$ were recorded and plotted cumulatively, as shown at 1 in Fig. 1. The results for *S*s #2 and 3 are correspondingly presented in Fig. 1. In each case the lower two curves represent the effects of the individual $S^D$s. The compound $S^D$ represented by the higher curves, is seen to have exerted greater control over the response than the components.

*Animal #4.* *S* was given standard bar training and placed on the following schedule:

| mult $S^D$VI 1′, | $S^\Delta$ ext, | $S^D$VI 1′, | $S^\Delta$ ext. | |
|---|---|---|---|---|
| $L_2$ | *No L* *No T* | *T* | *No L* *No T* | L: light T: tone |

After eight 4-hr sessions the discrimination criterion was reached. During an $S^D$ the average rate of responding was only 19 per min. To increase the animal's response rate, and thus perhaps the number of responses in extinction, fixed-ratio training was introduced.

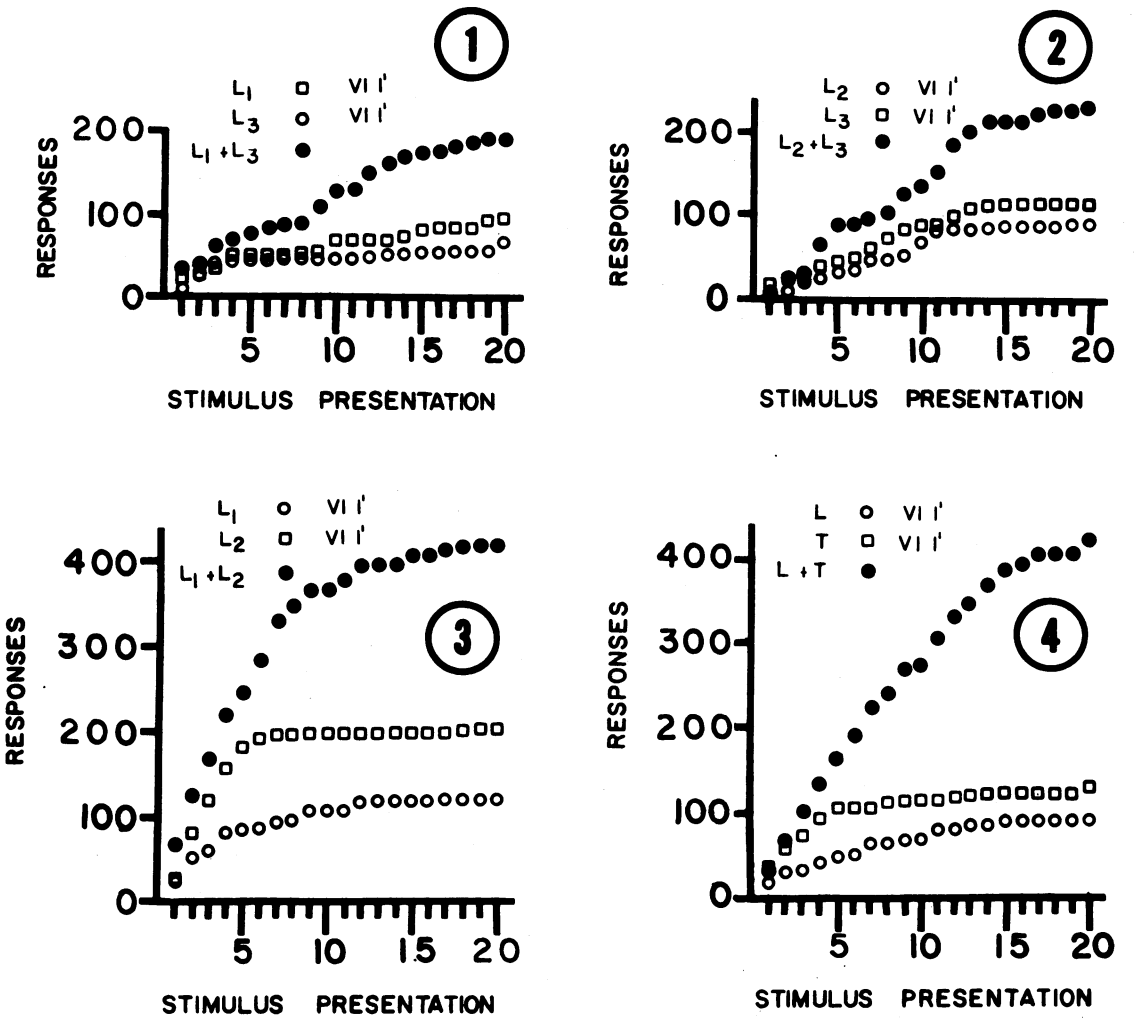


Fig. 1. Behavior during extinction. Comparison of cumulative responses for *Ss* Nos. 1, 2, 3 and 4 during 20 presentations each of two lights or a light and a tone and the combined lights or light and tone. The subscripts refer to the position of the lights. Bar pressing had been reinforced (VI 1′) in the presence of the individual stimuli while the combinations were first introduced during the test session. The individual and combined stimulus presentations were each followed by a period of no light (or no light no tone) which had previously been $S^\Delta$ (not shown). The duration of each presentation was 1 min. Note response attenuation as a function of time, and enhanced control when stimuli were combined.

In the presence of the $S^D$s, alternating in approximately 15-min intervals, ratio responding was shaped for two sessions. The first such session consisted of gradually increasing the required ratio to FR 25. The next session began with the first several reinforcers being obtained on FR 25. The ratio was then doubled to FR 50 for the remainder of the session. Approximately 200 reinforcers were received during the two ratio training-sessions.

At the next session, *S* was returned to the original multiple schedule where reinforcement was obtained on VI 1′ in the presence of the $S^D$s. After 12 sessions the criterion for discrimination was reached. The average response rate was 64 per min in $S^D$ and 6 per min in $S^\Delta$.

The testing procedure was identical to that described for *S* #1. The testing schedule was:

mult $S^D$ ext, $S^\Delta$ ext, $S^D$ ext, $S^\Delta$ ext, $S^D$ ext, $S^\Delta$ ext.

| | | | | | |
|---|---|---|---|---|---|
| *L* | *No L* | *T* | *No L* | *L+T* | *No L* |
| | *No T* | | *No T* | | *No T* |

The responses during each 1 min presentation

of an $S^D$ were counted electrically and then plotted cumulatively as shown at 4 in Fig. 1. As with the preceding subjects, the higher curve represents the effects of the compound $S^D$ and the lower two curves represent the components, a light $S^D$ and a tone $S^D$. In the presence of the compound the total amount of responding is well above the sum of the two components.

The $S^\Delta$ rates are not shown. However, the mean $S^\Delta$-$S^D$ ratio for all *Ss* was slightly higher (.12) for the test session than for the last day of training.

Under the slightly varied conditions with which each of the four *Ss* in Experiment I was trained, the combined $S^D$s clearly controlled a greater number of responses in extinction than did either $S^D$ presented separately. The number of responses controlled by each compound was at least slightly greater than the sum of the individual components.

*Experiment II*

*The effects of combined $S^D$s observed for three consecutive sessions during ongoing reinforcement.* Three lights, each separately made an $S^D$, were later combined. The effects of the compound were compared with the effects of the individual components under conditions of ongoing reinforcement for three consecutive sessions.

*Animal #5.* After bar training the animal was trained for five days on:

mult $S^D$VI 30″, $S^\Delta$ ext, $S^D$VI 30″,
$L_1$ No L $L_2$
$S^\Delta$ ext, $S^D$VI 30″, $S^\Delta$ ext.
No L $L_3$ No L

Each leg of this schedule lasted 4 min, and the session 2 hr. On the sixth day of training the schedule was changed to:

mult $S^D$VI 1′, $S^\Delta$ ext, $S^D$VI 1′,
$L_1$ No L $L_2$
$S^\Delta$ ext, $S^D$VI 1′, $S^\Delta$ ext.
No L $L_3$ No L

The length of each leg remained at 4 min. The complete session was extended to 4 hr.

After a total of 10 days of discrimination training the criterion was reached. The testing schedule consisted of:

mult $S^D$VI 1′, $S^\Delta$ ext, $S^D$VI 1′, $S^\Delta$ ext,
$L_1$ No L $L_2$ No L
$S^D$VI 1′, $S^\Delta$ ext, $S^D$VI 1′, $S^\Delta$ ext.
$L_3$ No L $L_1+L_2+L_3$ No L

The three testing sessions for #5 each lasted 6.4 hr, a total of 19.2 hr. The sessions occurred on three consecutive days, 12 presentations of the complete multiple schedule being presented each session. Each leg of the eight-ply schedule had the same durations as in training—4 min. The order of appearance of each $S^D$ was randomized for each presentation of the complete schedule except that no $S^D$ was allowed to follow itself directly in the next presentation of the schedule. The same order of $S^D$ appearance was used for all three sessions. The number of reinforcers and their temporal pattern of availability was held approximately constant for the $S^D$s in each single presentation of a complete schedule. Responses emitted during each 4-min $S^D$ period were counted electrically and plotted cumulatively for each of the three test sessions and are presented in Fig. 2. In the first set of curves, representing the first test session, the compound $S^D$ is clearly above the individual $S^D$s. However, in the remaining sessions, as exposure to the compound increased, its control decreased, the slope of the curves becoming more alike.

The $S^\Delta$ rate is not shown in Fig. 2. However, the $S^\Delta$-$S^D$ ratio changed slightly, increasing from .09 for the last session of training to approximately .15 for all three testing sessions.

## DISCUSSION

The summative effect of combined CSs reported by Hull (1943), and Pavlov (Kimble, 1960), was found in the present experiment to occur for combined $S^D$s.

If the separate stimuli and their compound are considered to make up a stimulus dimension along which stimulus generalization occurs, certain recent experiments where peak-shift generalization gradients were observed are relevant.

Peak-shift gradients have been produced by first programming differential contingencies in the presence of discriminative stimuli along some dimension. Later, the presentation of new stimuli along the discriminative continuum has produced generalization gradients involving a shift in the peak of control away from the original $S^D$ in the direction away from the $S^\Delta$.

Hanson (1959) reported the effect along a dimension of spectral wave length, and Pierrel

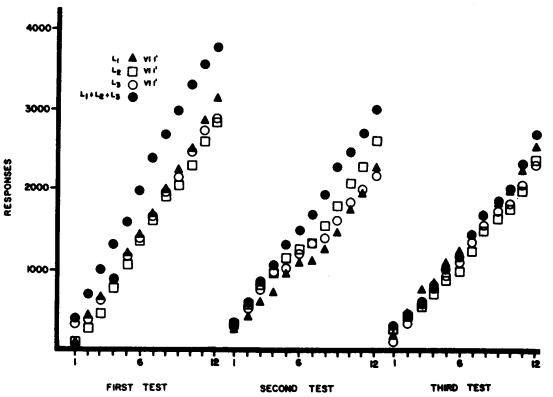


Fig. 2. Behavior during reinforcement (VI 1'). Comparison of cumulative responses for *S* #5 during three test sessions consisting of 10 presentations each of three separate stimulus lights and their combination. Bar pressing had been previously reinforced (VI 1') in the presence of the individual lights while the combination was first introduced during the test session. The individual and combined stimulus presentations were followed by a period during which all three lights were absent, a condition having previously been $S^\Delta$ (not shown). The duration of each presentation was the same as in training—4 min. Note attenuation of the enhanced control by the combination as a function of exposure.

and Sherman (1960) along an auditory intensity continuum.

These results and those of the present study are perhaps complementary. In each case, a new stimulus exerted greater control over the response than did the original $S^D$. However, the present example of enhanced control was not along a simple unitary stimulus dimension (wave length, intensity); rather, it involved the combination of stimulus components from the same as well as from different sense modalities. A procedural difference is then noted between the present experiments and those cited; here two or three $S^D$s were separately conditioned instead of one as in the above experiments. However, under either set of conditions the behavioral relationships observed may have been functionally similar. To take this point further, certain comparisons must be made. A difference in response strength implies the existence of three positions on the unitary stimulus continua: the $S^\Delta$, the $S^D$, and the $S^D+$, or the new stimulus which controls the greatest response strength. The analogous positions on the composite stimulus continuum are as follows: (1) the $S^\Delta$ point on this continuum is the absence of all $S^D$ stimulus components; (2) the $S^D$ point corresponds to the presence of either $S^D$ component; (3) the $S^D$ compound of the composite dimension corresponds to the $S^D+$ position on the unitary continua in that it is, in some sense, "farther away" from the $S^\Delta$. It might be assumed, then, that the present procedure involving an arbitrary composite stimulus dimension is functionally equivalent to the procedures involving unitary stimulus dimensions, and that the enhanced control of the combined $S^D$s is an example of peak shift along a composite stimulus dimension.

It is interesting to note that enhancement of CSs in respondent conditioning has been reported both with unitary auditory intensity continua (Razran, 1949; Hovland, 1937) and with combined CSs as previously described in this paper (Kimble, 1960; Hull, 1943). It would appear that enhanced stimulus control applies similarly to CSs and $S^D$s on both composite and unitary stimulus dimensions.

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