*SUMMATION OF RESPONSE RATES TO
DISCRIMINATIVE STIMULI ASSOCIATED WITH
QUALITATIVELY DIFFERENT REINFORCERS¹*

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In Experiment I, a four-ply multiple schedule was used to study the effects on rate of responding in rats of food, water, and food and/or water reinforcement under different deprivation conditions. Food and water were associated separately with different stimuli, the combination of which was associated with food and water together, or with food or water randomly. Rates in the presence of the combined stimuli were consistently intermediate to the rates generated by the separate stimuli, a result seemingly incompatible with a "summation" hypothesis. Experiment II was a simplified systematic replication of Experiment I, verifying the major findings.

Since Pavlov's time there has been a continuing interest in the summation of response "strength" under the control of different external stimuli. Operant investigators such as Kalish and Guttman (1957, 1959) have studied summation in the context of the generalization gradients obtained when responses have been reinforced in the presence of two or more separate stimuli (S^D s) in a single stimulus modality.

Other investigators have studied the effects of compounding separate S^D s in different stimulus modalities (e.g., Cornell and Strub, 1965; Weiss, 1964; Wolf, 1963). Generally, these experiments have shown that if the same response has been similarly reinforced in the presence of two different S^D s presented separately, there will be an increase over either of the two separate response rates when the two stimuli are presented together. The present experiments were also concerned with summation in the context of compounding stimuli.

In previous experiments on compounding stimuli, the same reinforcer has been used for both S^D s, and testing was carried out during extinction. Prior to extinction, the two S^D s were never presented in combination. Variations on this arrangement would be: (1) to test for summation effects with the same rein-

forcer for both S^D s during response maintenance, although this may not be "summation" as it is traditionally conceived; (2) to test for summation effects with qualitatively different reinforcers for each S^D during response maintenance; or, (3) to test for summation effects for qualitatively different reinforcers for each S^D during extinction. The present experiments studied the latter two arrangements.

If summation is to be tested while behavior is being maintained in the presence of the separate S^D s, then reinforcement must also be presented during the combined S^D s. Otherwise, the combined S^D s would become a stimulus complex indicating extinction. Two possibilities for testing summation while behavior is being maintained are: (1) to let the combined S^D s indicate that both reinforcement schedules associated with the separate S^D s are in effect simultaneously; or, (2) to let the combined S^D s indicate that either of the schedules may be in effect, but not simultaneously. The first procedure allows the combination of S^D s to serve the function of the logical "and"; the second procedure allows it to serve the function of "or" (exclusive).

Ferster and Skinner (1957, pp. 572-577) performed an experiment with pigeons which sheds light on the "or" function during maintenance when the reinforcers are qualitatively different, although their experiment did not involve stimulus compounding. They used a three-ply multiple schedule in which there were three different S^D s in the same modality. In the presence of one S^D , pecking was rein-

¹The research reported here was supported by Grant No. HD-00944, National Institutes of Health, awarded to the late Dr. Reed Lawson. Reprints may be obtained from Joseph J. Pear, Department of Psychology, University of Manitoba, Winnipeg, Manitoba, Canada.

forced only with food; in the presence of the second S^D, pecking was reinforced only with water; and in the presence of the third S^D, the scheduled reinforcer was either food or water on a random, 50 : 50 basis. The third S^D consistently produced a response rate between the rates produced by the other two stimuli.

Experiment I of the present study was concerned with the question of summation while behavior is being maintained when there are qualitatively different reinforcers for each S^D, and the combined S^Ds indicate that either ("or") or both ("and") reinforcers will be forthcoming. Naturally, the combined S^Ds probably would soon become a stimulus complex acting in a manner distinct from its component parts. Therefore, this may not be a "summation" test in the traditional sense. Nevertheless, it might be related closely enough to standard summation procedures for the effects of the "and" and "or" functions to contribute information about the "summation" process. With this in mind, Exp. II was conducted to determine whether the effects of the "and" or "or" procedures in Exp. I characterized the behavior that results when the stimulus complex is presented for the first time during an extinction test.

In addition to an interest in summation, the experiments were also prompted by an interest in the concept of generalized reinforcement (Skinner, 1957, p. 53). We felt that combined S^Ds, indicating that either or both of two different reinforcers would be forthcoming, might control responding in a manner similar to that of making a generalized reinforcer contingent upon responding.

EXPERIMENT I

A four-ply multiple schedule was developed. One ply was simply a period in which responses were not reinforced, and during which each response prolonged the non-reinforced period. This component is referred to as an "S^A with delay". Its purpose was to separate the other components, and to force the subjects to attend to the relevant stimuli. All other components were on the same variable-interval (VI) schedule, and were respectively associated with reinforcement by food alone, water alone, or both food and water. Extended series of observations were made under conditions of total deprivation (hungry and

thirsty) with appropriate reinforcement; extinction under total deprivation; partial deprivation (e.g., hungry but not thirsty) but all reinforcements presented, and complete satiation but all reinforcements presented. Because of the numerous "sub-experiments" actually performed, the Procedure section is a brief resumé of the overall strategy; more details are given as relevant in conjunction with the reports of the results.

METHOD

Subjects

Four male albino rats, 100 days old at receipt, were used. Their normal body weights, established over a month of free access to food and water, ranged from 350 to 450 g.

Apparatus

A standard commercially built free-operant chamber (Foringer & Co.) with the necessary control equipment was used. Only the left-hand lever was in the chamber during this experiment. The chamber was in a room isolated from the programming equipment, although other chambers, in use for other experiments, were present in the room. An air conditioner maintained temperature in the range 65° to 75° F; the air conditioning fan ran continuously to provide a general, constant masking sound.

Procedure

Subjects were reduced to and stabilized at 80% of normal weight over a three-week period by food deprivation alone. For three sessions shaping and continuous food reinforcement (CRF) for lever-pressing were instituted.

Water deprivation was then begun. This procedure consisted of allowing the subject access to a water bottle for 30 min each day just before normal feeding time. Enough food to maintain subjects at 80% weight was given when the bottle was removed. Simultaneously with the beginning of this regimen, 16 sessions of CRF for water were given.

Beginning with Session 20 the multiple schedule was inaugurated. There were four stimulus conditions, each associated with a different reinforcement procedure: (1) House-lights on (HL), these were two 6-w bulbs, with food reinforcement; (2) an 800-cps tone (T),

with water reinforcement; (3) both HL and T on (HL + T), both food and water reinforcement; and, (4) neither HL or T on, and differential reinforcement for any other behavior in effect (S^A with delay), *i.e.*, the subject had to cease responding on the lever for a prescribed period to terminate this phase. Condition (4) was used to separate the other periods from each other, thus minimizing superstitious behavior and forcing the subject to attend to relevant stimuli.

Condition (3), actually of two types for different subjects, was designed after Wunderlich (1961) who found that it made a difference whether both food and water were presented simultaneously, or whether they occurred (in the presence of the same stimulus) separately but randomly. Therefore, Subjects #4 and #5 were "and" subjects: they received both reinforcements together whenever reinforcement was programmed in the presence of HL + T. Specifically, a reinforced response would cause a dipper containing 0.2 cc of fresh tap water to become accessible for 1 sec. Withdrawal of the dipper automatically activated the feeder, dispensing a 45-mg food pellet (Noyes). The "or" subjects (#1, #2) simply received either water or a food pellet whenever a reinforcement was programmed during HL + T; all reinforcements during a given HL + T period were of the same kind, but were random from period to period.

On Session 20 the reinforcement schedule under all three positive conditions was VI 20-sec, and the S^A with delay periods lasted until 15 sec elapsed without a bar-press. A session was 2 hr long. Over the next 23 sessions, three parameters of this program were gradually increased. The average VI length was brought to a terminal value of VI 45-sec (always the same in all reinforced periods). The S^A with delay reached a value of 1 min. The third parameter was called "minimum S^D (discriminative stimulus) time." This simply meant that an S^D period was in effect until it was terminated by the first reinforcement occurring after a certain arbitrary length of time, which was the minimum S^D time. The terminal, and modal, minimum S^D time was 2 min.

As mentioned, an S^A with delay period always followed every S^D period, but the order of S^D periods was random. The probability of HL occurring was 0.25; that of T 0.25; and that of

HL + T 0.5. (Actually, the sequence was not strictly random since a stepping switch was used to program the occurrence of each S^D . However, each session began at a different position on the stepping switch.) For the "or" subjects, an approximately equal number of food and of water reinforcement contingencies occurred during HL + T periods. Sessions were given daily, at approximately the same time each day for each subject, except for an occasional interruption of a day or so. The terminal program ran for 33 sessions, making a total of 76 sessions, following which additional variations described below, were introduced.

RESULTS

Contrary to possible expectations, there were no apparent differences between the performance of the "and" and the "or" subjects at any stage of the experiment. Therefore, except where an understanding of the procedure requires it, the distinction will not be emphasized between these differences under the HL + T condition.

The effects of all procedures are summarized in Fig. 1, which shows the terminal response rates for each subject averaged over the last five sessions under a given procedure; in cases where fewer than five sessions were given, all sessions are averaged.

Column 1 of Fig. 1 shows the terminal performance on the basic multiple schedule, averaged over Sessions 72 to 76. Under these deprivation conditions, responding to food reinforcement was superior to responding to water reinforcement. Of much greater interest is the rate of responding to HL + T. It holds a semi-intermediate position (*i.e.*, "semi-intermediate" because it is not an exact average of the rates of responding to the stimuli for food alone and for water alone); a rapid survey of the entire series of histograms shows that this is where it almost invariably stayed.

Columns 2 and 3 of Fig. 1 show the effects of satiation on one reinforcement condition while continuing deprivation on the other. The actual procedure was somewhat more complicated than described in the legend of the graph. After Session 76, one "and" and one "or" subject (Subjects #4 and #1) were given free access to water for one week while the other two subjects were given free access

Fig. 1. Mean rates of responding in the three stimulus conditions for each subject under the following experimental conditions: (1) terminal performance on the multiple schedule with both food and water deprivation; (2) performance under food deprivation and free access to water; (3) performance under water deprivation and free access to food; (4) performance during extinction; (5) performance under food deprivation, free access to water, when alternated daily with (6) water deprivation, free access to food, and (7) performance with free access to both food and water. All histograms are based on the five terminal sessions of the condition described, except conditions (5) and (6) which are based on the only four sessions that were given in each case. For Subjects #2 and #5, condition (3) actually preceded condition (2). Since the order of presentation had no apparent effect, the conditions are shown in the same order for all subjects for ease of comparison. Subjects #1 and #2 received either water or food in the presence of HL + T, Subjects #4 and #5 received both at the same time. Note the lack of any marked differences in the performance of the two pairs of subjects.

to food. Then 15 sessions under the usual schedule were given while these deprivation conditions continued. After Session 91, the deprivation conditions were reversed for a period of 12 days: those formerly satiated with food were now satiated with water and *vice-versa*. A series of 12 additional sessions was run. Although the procedure was designed to control for possible sequence effects, these apparently did not occur (compare columns 2 and 3 of the quadrants in Fig. 1).

These differential deprivation data show two main points. First, there is a slight "contrast effect" (*cf.*, Logan and Wagner, 1965) wherein average rate on the unsatiated condition rises above the corresponding rate during the double-deprived condition. This could, however, simply indicate that subjects were not ordinarily getting enough water during

double-deprived sessions, thereby lowering somewhat the incentive value of food, instead of being true contrast. That the rate on the satiated condition drops only partially is, of course, trivial, except to verify the common observation that "satiation" of food or water independent of the other is a relative rather than absolute matter, *i.e.*, there is still substantial responding to the presumably satiated condition.

The second point is that while HL + T responding tends to drop somewhat, compared to the earlier baseline rate (two individual exceptions, see Subjects #2 and #5, Fig. 1), the drop is rather slight, compared to the drop in the satiated condition itself. This would tend to support the hypothesis that the presence in strength of only one of the original deprivation conditions is sufficient to maintain

the strength of a response reinforced by different reinforcers (see Skinner, 1957, p. 53).

At the end of Session 103 a series of six extinction sessions was scheduled under the just-completed deprivation-satiation combination for each subject. Because of the low rates of responding generated during extinction, the "minimum S^D period" procedure had to be discontinued so that subjects would be exposed repeatedly to all stimuli. The procedure used instead was simply to program arbitrary 2.25-min S^D periods, regardless of whether or not the subject responded. The S^A with delay condition presented no problems. The empty feeder and/or dipper operated as usual when a reinforcement would have been normally programmed.

Inspection of column 4 in Fig. 1 shows the effect of extinction. Overall rate is markedly reduced, of course, but more interestingly the rate in the presence of HL + T falls closer to or below the lowest rate for either of the single stimuli. In some cases the numerical differences are quite small, but they are all consistent with this statement. There is, naturally, a decline of rate under all conditions over extinction sessions, but there was no indication in the individual protocols that the HL + T rate declined more slowly, or in any other way differently from the rates under the separate stimuli.

Sessions 110 through 117 returned to shifting from one deprivation-satiation combination to another, with all reinforcement conditions as before, but the shifts were now made daily. The subject was satiated on one reinforcer one day, on the other the next, and so forth for eight days. Two subjects began on food deprivation, two on water (conditions that subjects had already been on for some time).

The data for the food-deprived and water-deprived days are shown separately in columns 5 and 6 of Fig. 1. This was a frankly exploratory attempt, primarily to see if the previous single-deprivation data could be recovered. The only unusual development was that the water-deprivation condition produced somewhat greater individual differences in relative responding to the different stimuli than had been characteristic of most of the data.

For 12 days subjects were given free access to both food and water and then a final series of tests under "complete" satiation was run (Sessions 118 to 123). Looking at the final

column of the figure, the effects of satiation were to decrease rate of responding almost as much as did extinction. The major difference was that responding in the HL + T regained its "semi-intermediate" position.

DISCUSSION

This experiment verified the findings of Ferster and Skinner (1957, pp. 572-577) who used pigeons, three separate stimuli in the same modality (instead of a cross-modal "stimulus summation" procedure), and what we have called the "or" condition. Moreover, in the present experiment, the "and" condition produced the same averaging effect in the presence of the combined stimuli as found in the "or" condition.

The obtained averaging effect in the "or" condition might be explained on the basis of reinforcement density. In the "or" condition there were fewer food reinforcements during the combined S^D s than during the S^D for food alone, and fewer water reinforcements during the combined S^D s than during the S^D for water alone. But the similar averaging effect obtained in the "and" condition cannot be explained in this way, because in this procedure the frequency of each reinforcer in the presence of the combined S^D s was the same as that in the presence of its separate S^D . Indeed, the "and" subjects received twice as many total reinforcers (food and water) in the presence of the combined S^D s than in the presence of the separate S^D s. Thus, while considerations concerning reinforcement densities may have led to a prediction of averaging in the "or" condition, similar considerations would have led to the opposite prediction, *i.e.*, summation, in the "and" condition.

A factor which might account for the averaging effect obtaining under both procedures in the present study could be the difference in rate between responding for food and responding for water. Weiss (1967), using a standard summation procedure in which the same reinforcer (food) was used for the single S^D s and the combination of S^D s was first presented in extinction, found that averaging rather than summation will occur if one component is a DRL 20-sec and the other a VI 30-sec. He interpreted his results as follows: "The intermediate response [rate] 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." The present results may reflect this phenomenon, although the rate differences between responding for food alone and for water alone were not nearly as great as those obtained for the two single stimuli of Weiss' (1967) study.

Another possibility is that water is somewhat aversive to an animal motivated primarily for food, and that food is somewhat aversive for an animal motivated primarily for water. Although it is not known whether or not water may have aversive properties for a hungry animal, it has been shown that thirsty rats will work to turn off a stimulus associated with food reinforcement (Pliskoff and Tolliver, 1960). Further, if an S^D indicating positive reinforcement is made to indicate punishment as well, response rate in the presence of that S^D will soon decrease while, at the same time, non-punished responding reinforced in the presence of another S^D will increase (Brethower and Reynolds, 1962).

The fact that "inhibition", rather than summation, was obtained in Exp. I suggests that an experiment more analogous to standard summation studies would be informative. Thus, Exp. II was carried out.

EXPERIMENT II

This was a simple corroborative study: the combined stimuli were tested (via extinction) after developing the discrimination to the single stimuli (and their related reinforcement conditions) alone. There was no S^A with delay.

METHOD

Subjects

Four male albino rats, naive, 175 days old, were used. Subjects III-2, III-3, III-4 ranged in normal weight from 430 to 436 g; III-1 was considerably larger, weighing 530 g.

Apparatus

The apparatus was exactly the same as used in Exp. I *i.e.*, a single-lever free-operant chamber. All other control equipment and the physical environment were as before.

Procedure

Subjects were started on combined food and water deprivation and reduced to the 80%

weight level. They were first given two 2-hr sessions of magazine training, shaping, and CRF for food reinforcement (45-mg Noyes pellets), then four sessions of the same kind for 0.2-cc fresh tap water. Then followed seven sessions on *mult* VI 20-sec VI 20-sec; in one component the houselight (HL) was on and responses were reinforced with food pellets, while in the other component the 800-cps tone (T) was on and the reinforcer was water. Beginning with Session 14 the program was changed to *mult* VI 45-sec VI 45-sec.

Sessions 14 to 33 were spent developing a stable discrimination between HL and T. This multiple schedule had been programmed so as to switch from one ply to the other after a random number of reinforcements. However, a persistent malfunction in the randomizing component caused a switch from one condition to the other after each reinforcement most of the time. This may have been a blessing in disguise, since it may have enhanced external stimulus control.

Another feature of the program imposed a maximum 90-sec duration on either stimulus condition. That is, if the subject did not make a reinforced response within 90 sec of the onset of a stimulus or within 90 sec after the last response in that stimulus, the next stimulus automatically came on. This was to protect against the fact that responding would occasionally cease for long periods during the water reinforcement phases. This did not occur often, however. The main effects of this procedure were to prevent extreme differences in rate in the two components and to insure a large number of presentations of both stimuli.

Sessions 34 to 36 were extinction sessions with HL, T, and HL + T. Extinction *per se* lasted 1.5 hr, being preceded by a 0.5-hr "warm up" on the usual *mult* VI 45-sec VI 45-sec schedule just described. During extinction, the components were programmed on a 21-position stepper, with each of the three components occurring once in each of seven blocks (order and sequence randomized from block to block). This series of 21 was repeated as many times as necessary, and any subject might have begun at any point on a given session. Changes from one component to another still occurred after "reinforcement" on VI 45-sec. Reinforcements were now the conditioned reinforcers of the feeder click (feeder tube de-

tached from food trough) in the presence of HL, sound of the dipper motor operating (dipper detached) in the presence of T, or both sounds in the usual "and" sequence (see Exp. I) in the presence of HL + T. The 90-sec upper limit was in effect as usual. Arranging for the primary reinforcers not to occur required that the sessions be momentarily interrupted and the chamber opened, which was unfortunate but necessary. This procedure showed no systematic effect, however, except perhaps to lower overall extinction rates.

RESULTS AND DISCUSSION

The terminal performances on discrimination training are summarized in the first portions of each segment of Fig. 2. It is clear that the typical effect was quite consistently obtained: subjects had lower rates for water reinforcement than for food. The inter-session stability (not shown) was quite good, excepting that Subject III-4 had a generally high, but variable performance level.

The extinction results are also shown in Fig. 2. Despite the generally low rates of responding, the results are quite stable. Rates in HL and T separately reflect the same differences as shown in reinforced multiple training, and, as found in Exp. I, rate in HL + T falls intermediate between the other two. The

evidence is consistent with the generalization that response tendencies based on food and water do not summate in the fashion that might have been expected of those based on two positive reinforcers.

In addition to providing information concerning summation, the experiments are also relevant to the concept of generalized reinforcement (Skinner, 1957, p. 53). It seems plausible that combined S^Ds, indicating that either or both of two different reinforcers would be forthcoming, might control responding in a manner similar to that of making a generalized reinforcer contingent upon responding. In Skinner's (1957, p. 53) words: "A step in the direction of destroying the relation with a particular state of deprivation is taken by reinforcing a single form of response in ways appropriate to many different states." In this connection note that data of Exp. I show that reducing deprivation for a single reinforcer reduced responding for that reinforcer alone to a greater extent than it reduced responding in the presence of the combined S^Ds (see columns 2 and 3 of the quadrants in Fig. 1). However, the data as a whole suggest that a response maintained by a simple secondary reinforcer may exist in higher strength (assuming that rate is a measure of "strength") than one maintained by a generalized reinforcer.

Fig. 2. Mean rates of responding in each stimulus condition during the last five two-ply multiple sessions (D) and the three subsequent extinction (E) sessions, 34 to 36, for each subject and all subjects combined.

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Received 13 April 1967.