SOME EFFECTS OF TWO TEMPORAL VARIABLES ON CONDITIONED SUPPRESSION

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Estes and Skinner (1) have shown that operant behavior can be suppressed by the presentation of a stimulus that has been paired previously with an electric shock. In this demonstration of what the authors referred to as "anxiety" effects, a warning stimulus of fixed duration followed by a brief unavoidable shock to the feet was superimposed upon ongoing lever-pressing behavior maintained by a fixed-interval reinforcement schedule. Two values of the warning-stimulus duration (3 and 5 minutes) were reported in this study, and the one or two presentations of the stimulus and shock during 60-minute experimental sessions permitted only limited coverage of the inter-stimulus intervals. In the present study, attention was directed at the effects of these two temporal variables upon conditioned suppression: (a) the duration of the stimulus paired with the shock, and (b) the interval between these stimulus presentations (referred to subsequently as the between-stimulus or stimulus-off interval).

METHOD

Subjects

Five male albino rats, approximately 90 days old at the start of the experiment.

Apparatus

The experimental space was a metal chamber with a lever in one wall, electrifiable walls and grid floor, a speaker for presenting the auditory stimulus (a clicking noise), and a retractible dipper which presented a 0.05-cubic centimeter water reward for a 3-second interval. White noise in the experimental room masked auditory cues resulting from the operation of control apparatus located in a separate room.

The experimental procedures were programmed automatically with relay and timing circuits. Counts of response frequencies in the stimulus and between-stimulus intervals, the number of shocks, and the number of water reinforcements were recorded on electrical-impulse counters, and a cumulative recorder provided continuous records of lever-pressing.

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Preliminary Training

Preliminary training involved habituation to the watering regimen, magazine training (180 reinforcements), continuous reinforcement for lever-pressing (100 reinforcements), and 1-minute, variable-interval (VI) training (7 hours). Three animals, AM-1, AM-2, and AM-3, received all subsequent training in 2-hour sessions every day except weekends and holidays. These Ss were allowed free access to water for 15 minutes daily following the experimental session. The two remaining animals, AM-4 and AM-5, received training on alternate nights, usually in 3-hour sessions. (In the case of some conditioned-suppression programs, the sessions were longer so as not to end in a stimulus period.) These Ss were given water for 1 hour on the mornings after experimental sessions. The three "day" animals completed preliminary training with 30 hours of 2-minute VI; the two "night" animals received 12 hours of 2-minute VI, and, finally, 40 hours of 3-minute VI. The night animals were switched to 3-minute VI to reduce satiation effects on their longer sessions. The VI schedules were set up in such a way that the programming tape stopped when a reinforcement was set up, and continued its cycle after the reinforcement had been delivered. The sequence of intervals in the 2-minute schedule was 140, 20, 120, 200, 100, 10, 220, 40, and 230 seconds; and in the 3-minute schedule, it was 80, 180, 10, 330, 240, 30, 280, 120, and 350 seconds.

Conditioned-suppression Training

Each animal received training on a series of different conditioned-suppression programs. All programs can be described as the repetitive cycling of three events: (a) an interval of VI reinforcement (2-minute VI for the day animals, 3-minute VI for the night animals) with no stimulus presented; (b) an interval of VI reinforcement in the presence of the auditory stimulus; and (c) a 0.5-second shock (1.0 milliampere) presented at the termination of the clicker. The experimental design involved the joint manipulation of the durations of the stimulus-off and stimulus intervals.

Figure 1, which presents the data in chronological order, indicates the sequence of programs given each S and the number of sessions of each program. An attempt was made to maintain each interval-combination program for 40 experimental hours before switching to the next, but deviations from this plan occurred if behavior on a given program had not stabilized, or if an error in procedure necessitated the discarding of data.

Values of the between-clicker and clicker intervals were selected during the experiment, and were based on experimental findings rather than a pre-conceived plan. An attempt was made to survey a wide range of intervals.

RESULTS

The average rates of responding in each daily session in the clicker and in an equivalent period prior to the clicker were computed for each S. This was not possible, of course, for programs in which the stimulus-off interval was shorter than the stimulus interval. In these cases, average response rates for the entire stimulus-off interval were used. A daily index of behavioral suppression was then calculated by dividing the response rate in the clicker by that in the clicker-off period. These data are shown in Fig. 1.

Three aspects of the data deserve mention. First, the degree of suppression varied widely between interval-combination programs. Viewed roughly, programs in which the clicker duration was short, relative to the between-stimulus duration, tended to produce good suppression (indicated by small suppression ratios), while those in which the clicker duration was relatively long produced poor suppression (high ratios). The absolute values of neither the stimulus interval (e.g., compare "16 OFF - 4 ON" and "2 OFF - 4 ON") or the between-stimulus interval (e.g., compare "5 OFF - 1 ON" and "5 OFF - 5 ON") were importantly related to the strength of suppression.

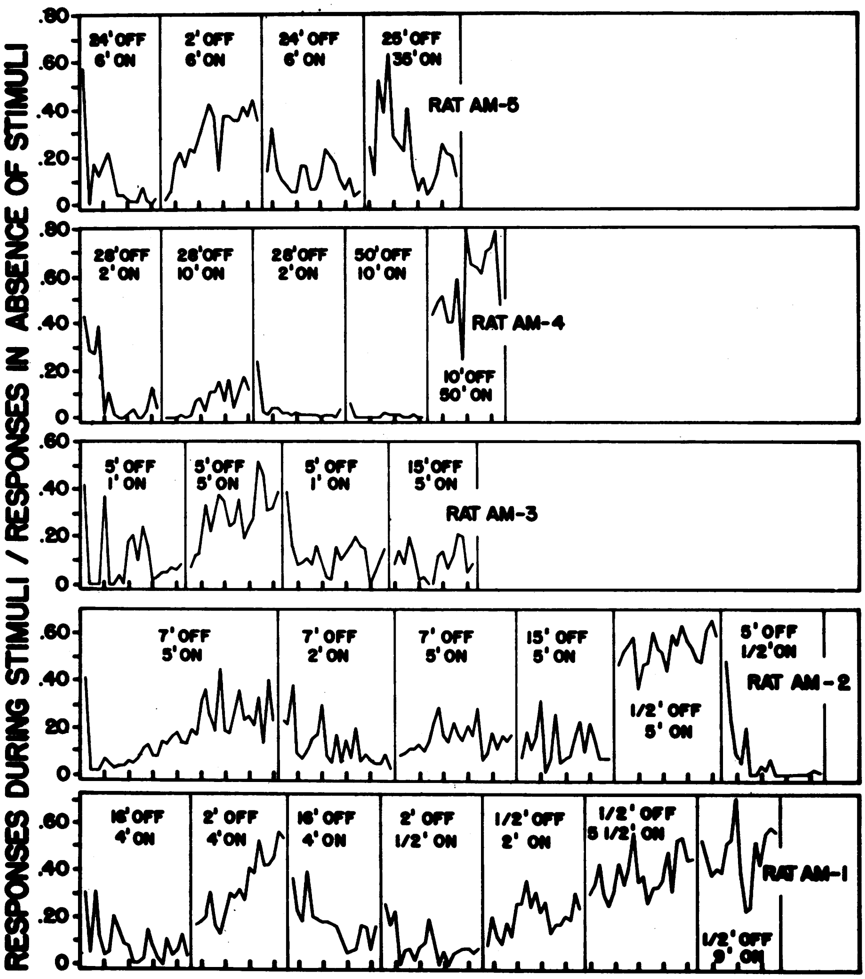

Fig. 1. Behavioral-suppression scores for the entire experiment. There are five sessions between abscissa markings within a given program.

Second, the effects of manipulating the clicker and between-clicker intervals were largely reversible. This is seen most clearly in the data of the first three programs, which involved, for all Ss, a return to the original intervals after interspersed training on a markedly different program. Figure 1 shows that the final level of suppression in the third program closely approximates that in the first program, even for those animals (AM-1, AM-3, and AM-5) showing large changes in the second program.

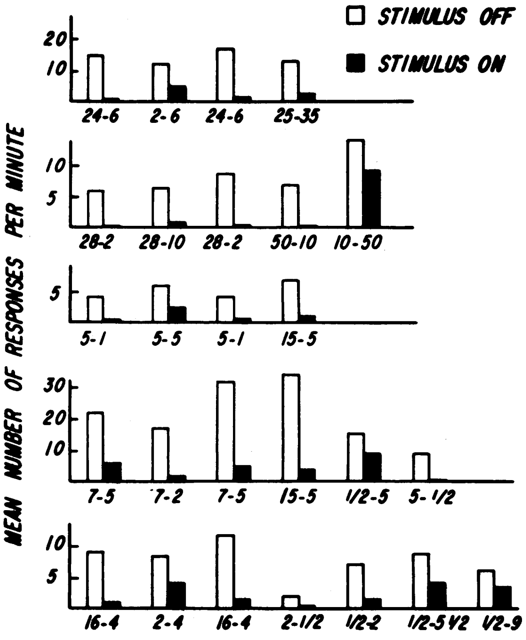

Fig. 2. Mean rates of responding in the stimulus-off and stimulus intervals in the last five sessions of each interval-combination program. S's are represented in the same order as in Fig. 1.

Finally, the changes produced by manipulating the experimental variables usually took hold gradually. The gradual nature of the transitions suggests that the adaptation to a new program may involve subtle learning processes. (See DISCUSSION below.)

Figure 2 presents the mean rates of responding in the clicker and between-clicker intervals for the last five sessions of each program. These data are presented primarily to show that the changes in suppression discussed above actually reflect changes in the rate of response in the clicker, and are not artifacts of rate changes in the clicker-off period. (For instance, examine the first three programs for each S for reversibility of response rate in the clicker.) It should be noted, however, that these averaged rate data do not present a complete picture of the performances. Cumulative records for many of the programs often exhibited different types of curvature in both clicker and between-clicker periods. Figure 3 presents some examples of commonly observed curvature, though it must be emphasized that the type of curvature within a given program was not necessarily invariant from one stimulus presentation to the next.

DISCUSSION

The results of these experiments indicate clearly that the relative duration of the stimulus paired with shock and the interval between such stimulus presentations is an important determinant of the degree of suppression observed in the Estes-Skinner conditioned "anxiety" situation. To examine this quantitatively, a "relative-duration" index, expressed as the ratio of clicker duration to between-clicker duration, was calculated for each interval-combination program (column 2, Table 1) and compared, on the behavioral side, with the average-suppression ratio for the last five sessions of each program (column 3, Table 1). Figure 4 shows these relative-duration ratios (transformed logarithmically) plotted against the suppression scores and reveals a linear trend in the relationship. A product-moment

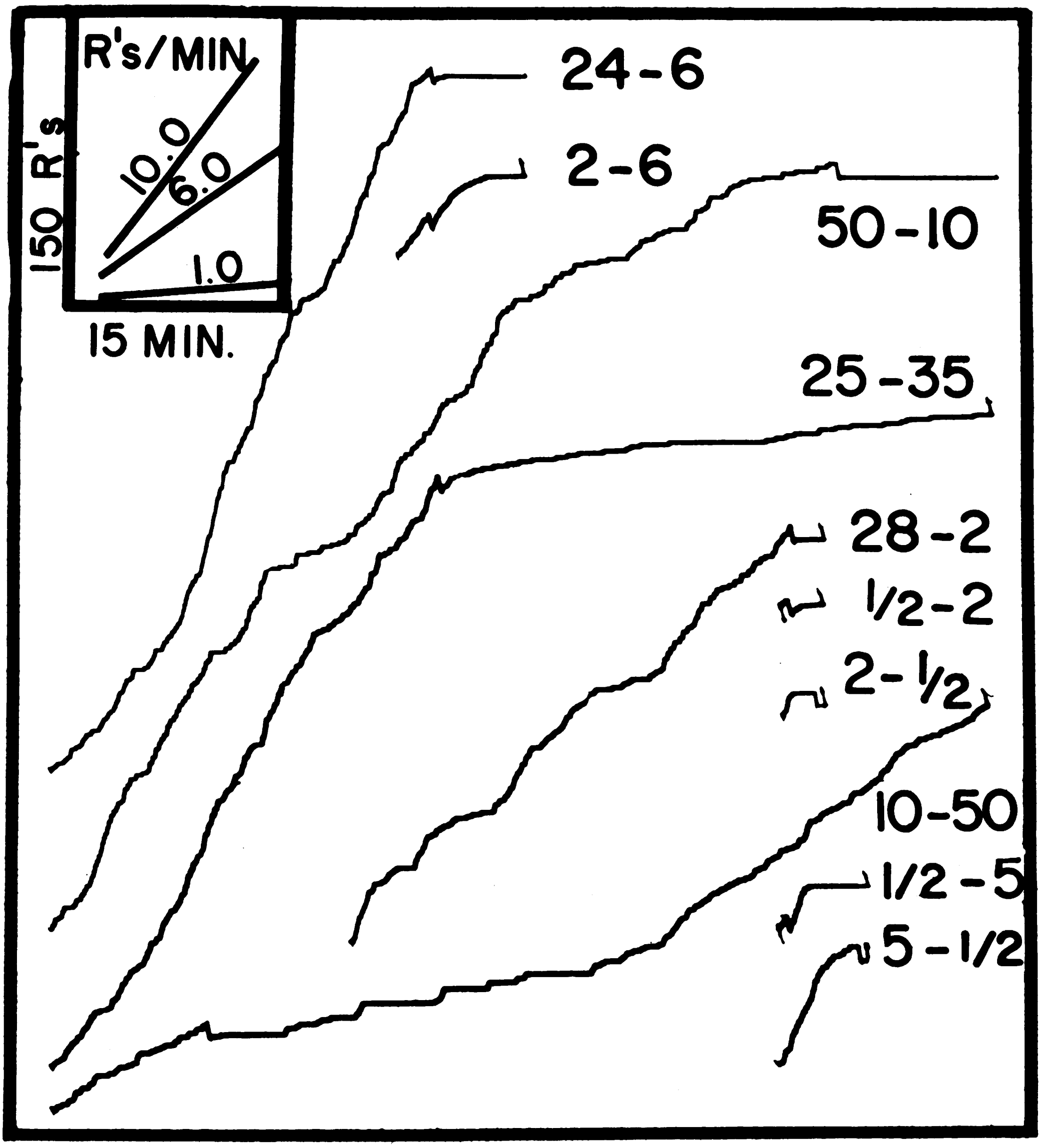

Fig. 3. Sample cumulative records taken in various interval-combination programs. The first number of each pair designates the between-stimulus interval; the second number, the stimulus duration. The vertical displacement on each curve indicates stimulus onset.

correlation of the pairs of scores, following the logarithmic transformation, gave r = 0.90, a highly significant value for 26 pairs.

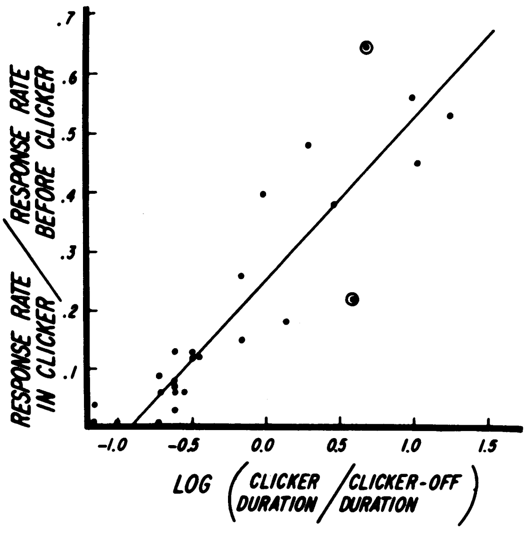

Fig. 4. Behavioral suppression as a function of log relative-duration ratio. The line was drawn by eye.

The demonstration of so substantial a relationship would seem to provide a satisfactory point of termination. There are, however, considerations that argue against this. First, it may be pointed out that such a variable as the ratio of stimulus and between-stimulus durations has little psychological meaning. In what way can the relative-duration ratio be presumed to have a direct effect on a rat's behavior? Variations in this ratio are probably correlated with changes in some contingency or set of contingencies that make direct contact with the behavior.

With this consideration in mind, the plot in Fig. 4 may be critically re-examined. Note that the relationship apparently breaks down at its extremes, particularly at the upper end (high ratios). A striking instance of this is given by a comparison of programs "1/2 OFF - 2 ON" and "10 OFF - 50 ON" (the circled points); while these programs differ negligibly in their relative-duration scores, their corresponding suppression ratios show a difference of almost 70% of the total ordinate scale.

Uneasiness with the relative-duration ratio is most strongly provoked, however, by an additional set of data. The fourth column of Table 1 presents the mean number of water reinforcements that were earned during the last five sessions at each interval combination, expressed as a percentage of the maximum number obtainable in an experimental session. These figures show the animals to have been earning reinforcements rather efficiently at approximately 90% of maximum. The relatively small variations exhibited no apparent systematic relation to the temporal parameters of the conditioned-suppression program. This relative constancy was maintained in spite of the wide differences in suppression found among the various programs.

This finding suggested that, after sufficient training, animals will suppress in the stimulus period only to an extent that does not markedly reduce opportunities for positive reinforcement. In some interval-combination programs, as will be shown below, complete suppression during the clicker period will not appreciably reduce the number of reinforcements that can be obtained in a daily session, as nearly all that set up in the stimulus period can be claimed shortly thereafter in the following stimulus-off period. In other programs, however, complete suppression in the clicker will markedly reduce the total number of reinforcements that can be earned in an experimental session. In these programs, much time frequently will elapse between the priming of a reinforcement in the clicker period and the onset

Table 1

Relative Duration Ratios, Suppression Ratios, Reinforcements Obtained, and Reinforcements-Missed-If-Suppressed Estimates for Each Interval Combination Program

Intervals Off(min.) - On(min.)	Relative Duration Ratio (on/off)	Mean Suppression Ratio Rate in Clicker / Rate Before Clicker (last 5 sessions)	Mean Reinforcements Obtained as a Percentage of Maximum Obtainable (last 5 sessions)	Estimate of Reinforcements Missed-If-Suppressed in Clicker as a Percentage of Maximum Obtainable
1/2 - 2	4.00	.22	84	32
1/2 - 5	10.00	.56	78	65
1/2 - 5 1/2	11.00	.45	77	68
1/2 - 9	18.00	.53	89	79
2 - 1/2	0.25	.06	89	03
2 - 4	2.00	.48	92	43
2 - 6	3.00	.38	84	48
5 - 1/2	0.10	.01	97	01
5 - 1	0.20	..06,.09	92,89	04
5 - 5	1.00	.40	84	36
7 - 2	0.29	.06	95	09
7 - 5	0.71	.26,.15	90,95	30
10 - 50	5.00	.65	92	80
15 - 5	0.33	.13,.12	92,92	18
16 - 4	0.25	.08,.13	90,94	13
24 - 6	0.25	.03,.07	89,94	13
25 - 35	1.40	.18	92	55
28 - 2	0.07	.04,.01	89,92	02
28 - 10	0.36	.12	76	21
50 - 10	0.20	.00	84	13

of a stimulus-off period in which the reinforcement may be obtained. It will be shown that it is these programs that produce poor suppression.

For such a demonstration, it is necessary to estimate, for every program, the number of reinforcements that would be missed in an experimental session if an animal were to suppress completely in the stimulus. (It should be explicated that this entire development pertains to the use of a VI schedule in which reinforcement opportunities are reduced if sufficient time elapses between primings of the magazine and occurrences of a response.) As suggested above, the estimate of reinforcements missed is proportional to the total amount of time elapsed in the stimulus periods <u>after reinforcements have been set up</u>-- the constant of proportionality being equal to the reciprocal of the mean VI duration. The computational procedures for obtaining this "reinforcements-missed" estimate are given in a terminal note; it will suffice here to point out that this computation depends on three factors: (a) the duration of the stimulus interval; (b) the number of stimulus intervals in an experimental session; and (c) the exact distribution of inter-reinforcement intervals in the VI schedule. Since (a) and (b) jointly define the interval-combination program (when the length of the experimental session is fixed), a high correlation may be expected between this reinforcements-missed-if-suppressed variable and the relative-duration ratio.

The last column of Table 1 gives the results of these calculations for each interval-combination program; the reinforcements-missed estimates are expressed as a percentage of the maximum number of reinforcements obtainable in an experimental session. A plot of these data against the mean suppression ratios appears in Fig. 5. The obtained relationship may be seen to be approximately linear; a calculation of the product-moment correlation gave r = 0.92.

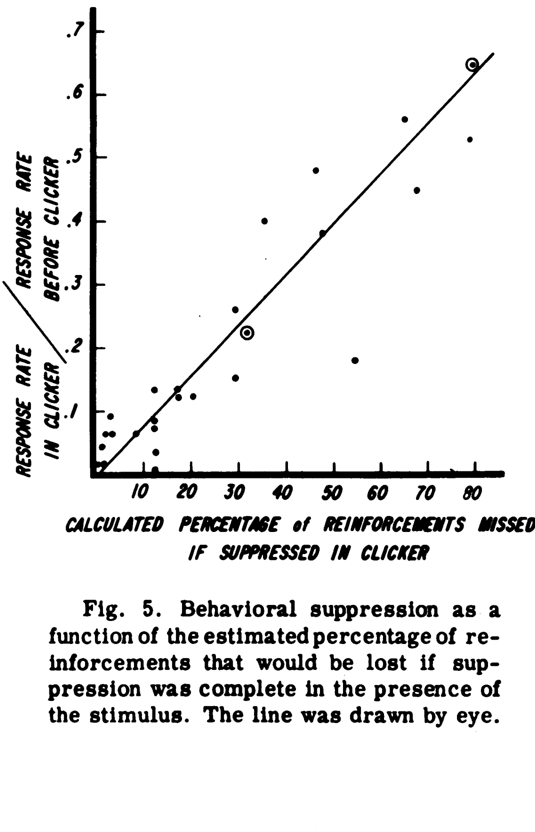

Fig. 5. Behavioral suppression as a function of the estimated percentage of reinforcements that would be lost if suppression was complete in the presence of the stimulus. The line was drawn by eye.

Although this correlation is approximately the same as that obtained with the (log) relative-duration measure, an accounting of suppression in terms of the reinforcements-missed formulation is undoubtedly preferable, if correct, to a bare statement of relationship between relative-duration ratio and suppression. Furthermore, as suggested above, there is reason to believe that the relative-duration ratio is only indirectly a major determiner of suppression, and that its apparent potency derives from a high correlation with the reinforcements-missed measure. Under the conditions of the present experiment, the correlation between the log relative-duration ratio and the reinforcements-missed estimate is 0.94. This value is sufficient to account for the correlation of 0.90 between log relative duration and suppression, as the correlation between the reinforcements-missed estimate and suppressions was 0.92.

A correlation of 0.94 between relative duration and reinforcements missed means that it will be difficult to choose between these two alternative explanations. The ordering of the various interval-combination programs in terms of one of the variables is practically identical with that given by the other. For a few programs, however, these measures are not closely equivalent. The two most striking cases of nonproportionality are furnished by the programs "1/2 OFF - 2 ON" and "10 OFF - 50 ON," the circled points in Fig. 4 and 5. The large difference in suppression between these programs, which was a "discrepancy" in terms of the relative-duration ratio (Fig. 4), is nicely in accord with prediction on the basis of the reinforcements-missed estimate (Fig. 5). Close inspection of the two figures reveals that the reinforcements-missed measure yields a generally more regular linear relationship throughout, although the difference is necessarily small. Further research involving the selection of programs that clearly differentiate the two variables, as well as manipulations of other variables (e.g., the reinforcement schedule), will provide a more rigorous evaluation of the reinforcements-missed formulation.

SUMMARY

1. The present experiment investigated two temporal variables in the Estes-Skinner conditioned-suppression situation. The five animals were given prolonged training on a series of conditioned-suppression programs; the programs differed from each other with respect to the stimulus and between-stimulus durations.

2. The degree of suppression varied widely from program to program. Roughly, programs in which the stimulus duration was short relative to the duration of the stimulus-off interval produced good suppression, and programs in which the stimulus duration was relatively long produced poor suppression. These effects were largely reversible.

3. "Relative duration," defined as log (stimulus duration / stimulus-off duration), correlated 0.90 with the degree of behavioral suppression.

4. The number of reinforcements obtained in each program was relatively constant at approximately 90% of the maximum number obtainable in an experimental session in spite of the wide differences in suppression.

5. An estimate of the percentage of reinforcements that would be lost if the animal suppressed completely in the stimulus period was calculated for each conditioned-suppression program. This measure correlated 0.92 with suppression scores, indicating that the strength of suppression in any program decreases to the extent that such suppression reduces opportunities for positive reinforcement. Evidence was presented suggesting that the relative-duration variable appeared to have a major effect on suppression only because this variable correlated very highly (0.94) with the reinforcements-missed measure.

NOTE

Procedure for Estimating the Percentage of Reinforcements That Will Be Lost in an Experimental Session if an Animal Suppresses Completely in the Stimulus Period

As indicated in the text, these computational procedures are valid only for VI schedules that "lock up" with the priming of a reinforcement. The procedure below is a means of estimating the total "lock-up" time in the stimulus periods of a conditioned-suppression program when suppression is complete in the stimulus. The number of reinforcements that must be lost under these conditions is proportional to this total lock-up time.

Consider the interval-combination program X : Y, where X = stimulus duration and Y = stimulus-off duration. The first problem is to estimate the expected amount of lock-up time in any X (stimulus) period. We need to know, in addition to the value of X, two things: (a) which inter-reinforcement interval of the VI schedule happens to be in force at the onset of the stimulus, and (b) how much of that interval has elapsed prior to the onset of X.

Since the intervals of the VI schedule may be considered to be randomized with respect to stimulus onset, we cannot specify (a) and (b) for particular stimulus periods; however, we can give mean estimates for a large number of stimulus periods. For this purpose, we assume that any interval may be in force at the onset of the stimulus, and specify the likelihood of a given interval as its relative duration (duration of interval / sum of durations of all intervals).

Again, since the intervals occur randomly with respect to stimulus presentations, it is equally likely for any portion of the interval to have elapsed at the onset of X. The value of the unexpired portion of any interval, then, may range from zero to the entire duration of the interval (I), with equal weighting for every point within this range. The unexpired portion is, therefore, on the average, equal to I/2. Average lock-up time in the stimulus for interval duration I is X - I/2. Estimated lock-up time in X when all intervals are possible, then, is the weighted average of the individual average lock-up times, or

$$L = \sum d_i \left[(X - 1/2\, I_i) \right], \qquad (1)$$

where $\underline{L}$ = estimated lock-up time, $\underline{d_i}$ is the relative duration of interval $\underline{i}$, and $\underline{I_i}$ is the duration of $\underline{i}$. This estimate of lock-up time for one X is then multiplied by the number of X's in an experimental session to give total lock-up time. Finally, the value for total lock-up time is divided by the mean inter-reinforcement interval of the VI schedule to give the estimated number of missed reinforcements.

It must be pointed out that computational formula (1) holds only when I is equal to or less than X. If I is greater than X, there will be some occasions when reinforcements do not lock up in X, i.e., those occasions when X comes on near the beginning of the interval. In these cases the computation is handled by dividing the unexpired portions of I into two classes: those which range in value from 0-X, and those that exceed X in duration. The average lock-up time for the 0-X class (by the logic above) is X - X/2 or X/2; the average lock-up time for the greater-than-X class is, of course, zero. Mean lock-up time (L) for the entire interval is the weighted average of the lock-up times of the two portions, or

$$L = X/I\,(X/2) + (I - X)/I\,(0) = X^2/2I$$

REFERENCE

1. Estes, W.K., and Skinner, B.F. Some quantitative properties of anxiety. J. exp. Psychol., 1941, 29, 390-400.