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GRADUAL STRENGTHENING OF *S-R* CONNECTIONS OR INCREASING NUMBER OF *S-R* CONNECTIONS*[1]

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A. THE PROBLEM

In the typical learning experiment, only some facet of a series of situations is singled out for notice. Gradual increments often occur in the percentage of occasions this facet of the stimulus-situations is followed by some noted facet of the response-patterns. Classical learning curves show such increments.

The fact that the noted piece of the stimulating situations *is followed* with increasing frequency by some particular response often is assumed to mean that that *S is evoking* that *R* increasingly often. This assumption, in turn, leads to the idea that an increasing "probability of response" is due to a gradual strengthening of "the" *S-R* connection. However, gradual increments in P_{R+} may be due instead to other factors, and not to gradual strengthening of any *S-R* connection.

For example: (*a*) In addition to the stimuli we customarily note, many other stimuli are present. These stimuli too may be partial determiners of what response is elicited. Further, these stimuli may differ appreciably from trial to trial. When many different stimuli must become cues for R_+, and not all of them are present on any one learning trial, P_{R+} will increase gradually with N as more and more stimuli become cues for R_+ (cf. Postulate 3 of Guthrie's theory—Voeks 1950). Under such circumstances, *the P_{R+} should increase gradually even though each of the S-R connections is established fully with one pairing of that S and R.* (*b*) When the on-trial and between-trial stimuli are highly similar (as is usually the case), there are consequent opportunities between trials for extinction of some desired *S-R* connections, and P_{R+} can increase only gradually. (*c*) When different individuals first make the desired *R* on different trials, grouping the data will cause P_{R+} to increase gradually with N—even though every subject estab-

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lished the desired *S-R* with full strength when that *S-R* pairing first occurred for him.

The three circumstances listed above may be among the primary causes of gradualness in the P_{R_+} increments. This proposition is supported by data previously reported (9). The experiment here reported furnishes additional data bearing on the first two possibilities. It also tests Theorems 7 and 8 deduced (8) from Guthrie's postulates of one-trial learning, one-trial unlearning, postremity, and response-probability being proportional to the percentage of all present stimuli which are cues for that response.

Theorem 7 states: In any specified number of trials after the first R_+, more alternations in response will occur on the average for subjects in a relatively less stable situation than for subjects in any relatively more stable situation—when (*a*) not more than half the total stimulus-pattern after the first R_+ is consistently composed of stimuli which are not cues for R_+ and (*b*) the response between trials is R_i.

Theorem 8 states: In any specified number of trials following the first R_+, longer consecutive series of R_+'s will be made on the average by subjects under relatively more stable stimulus-conditions than by subjects under relatively less stable conditions.[2]

B. Method

1. *Subjects and Apparatus*

The 105 *S*s were male undergraduates of Yale University. None had studied conditioning. Twenty-five *S*s were used in preliminary tests to ascertain that no on-trial stimulus evoked R_+ before conditioning; 32 *S*s in experimental Group 1; 12 in each of four other experimental groups. The *S*s were assigned to the five experimental groups and run in a predetermined random order.

The apparatus is described elsewhere (9).

2. *Procedures*

Various conditioning procedures were used. For all groups, R_+ was a partial or complete blink or wink; the *US*, an air-puff;[3] and one of the main

[2]The following definitions were involved in the deductions of the above theorems: R_+ is the response *E* is interested in cuing to the on-trial stimulus-patterns; and R_i is any response incompatible with R_+. An *alternation* is any occasion when R_i is made on some trial and R_+ is made on the next, or when R_+ is made on some trial and R_i is made on the next. A *relatively stable situation* is, roughly, a set of trials which, compared to some other series of trials has (*a*) greater similarity of the stimuli from trial to trial, and (*b*) greater dissimilarity of the on-trial and between-trial stimuli. For more complete definitions, see 8, pp. 357-358.

[3]The air-puff was caused by the fall of 100-130 mm. of mercury, magnetically re-

CS's, a markedly damped buzz beginning about .45 sec. before the puff and ending about .09 sec. after onset of the puff. The inter-trial times were 45, 50, 55 . . . 75 sec., arranged in the same predetermined random order for all *S*s.

Five experimental conditions were designed to have progressively decreasing stimulus-stability. Decreasing stimulus-stability was accomplished by progressively dropping controls used for Group 1 to reduce variations in on-trial stimuli and to reduce similarity of on-trial and between-trial stimuli.

a. Procedure 1 (greatest stimulus-stability). Each trial began with *S* breathing in rhythm to *E*'s slowly saying "Ready, inhale, exhale, inhale, hold." On the last "inhale," *S* inhaled deeply. In response to "hold," *S* held his breath and "with as short a reaction time as possible" depressed a stiff telegraph key with each hand. This was done in a manner described to *S* in detail and practiced before the trials began. Depression of both keys activated the buzz. When the buzz terminated, *S* released the keys and ceased holding his breath. The *S* was told that this was "a study of individual differences in reaction-time," a statement made highly plausible by the procedure and apparently accepted by all *S*s.

Additional controls were introduced to minimize stimulus-variations arising from autonomic changes during the experiment, from differences in what the *S*s were thinking about, from changes in their set, from fluctuations in other internal stimuli, and from variations in the external stimuli. A more adequate description of these controls is published elsewhere (9).

b. Procedure 2. The key-response was dropped, less effort was made to create and maintain a constant state of calmness in *S*, and the stated purpose of the experiment was changed. These *S*s were told, "This is an experiment in reactive sensitivity. . . ." Far less plausible than the stated purpose for Group 1, this resulted in questions after the session concerning the purpose of the experiment. Probably these *S*s had questions *during* the experiment also, which could introduce considerable stimulus-variability from changes in set.

c. Procedure 3. The breathing routine was dropped, though the key-response was used. Trials began by *E* saying "Ready," and after 1 to 7 seconds, "now." In response to "now," *S* depressed the telegraph keys. The other sources of stimulus-instability present under Procedure 2 were present here.

Deleting the breathing routine decreased stimulus-stability in three ways:

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leased. Pressure of the puff was adjusted to each *S*'s sensitivity and elicited practically a full wink on each trial.

(*a*) The highly constant and extensive pattern of on-trial stimuli arising from holding one's breath after a deep inhalation were eliminated. (*b*) The on-trial and between-trial stimuli no longer were as dissimilar. (*c*) The key-response, though included, no longer could create very stable stimuli. Without the breathing routine and with no other stable pattern of cues substituted, a more variable pattern of stimuli evoked the key-response. Since a response is a function of the stimuli to which it is made, when the stimuli evoking the key-response vary, the key-response also varies. Consequently, *S* made the key-response in a considerably more variable fashion than under Procedure 1 and the stimuli from it no longer would be very stable from trial to trial.

Whereas eliminating the breathing routine unstabilized somewhat the key-response and consequently the stimuli arising from it (in Procedure 3), eliminating the key-response did not unstabilize the stimuli arising from the breathing routine (in Procedure 2). Mainly because of this fact, Group 3 should have had somewhat less stimulus-stability than Group 2. Both groups, of course, would have had considerably less stimulus-stability than Group 1.

d. Procedure 4. Neither the key-response nor the breathing routine were used. In addition, the door to the soundproof room was opened; *S* talked with *E* between trials, and *E* moved audibly between and during trials, occasionally rustling papers and shuffling her feet, thus introducing other adventitious variations in the on-trial stimuli.

e. Procedure 5. All variations in stimuli present under Procedure 4 were present here, plus some other extraneous stimuli varying from trial to trial—a faint light, a soft bell, and/or a click. One or two of these stimuli were presented on various trials, with varying time relationships to the buzz. No effort was made here to have the *S*s in a constant state of calmness.

3. *Number of Trials*

The mean number of total trials and the mean number of trials following each *S*'s first R_- are given in Table 1. Both should be equated for the various groups. However, before seeing the photographic records of the response, *E* could not always tell whether a deflection of the light from the eyelid-lever had arisen from a response properly classified as R_+ or whether it had resulted from a shift in gaze or some other incidental response. Therefore the numbers of trials following the first R_+ are not identical for the various groups, but there are no significant differences in either the means or the variances and no systematic differences from group to group.

Although the number of trials was small to avoid (for Group 1) increas-

TABLE 1
NUMBER OF TRIALS

Group	Mean number of total trials	Mean number of trials after and including the first R_+
1	17.2	13.5
2	14.8	12.8
3	15.2	12.2
4	14.8	13.1
5	15.6	12.8

ing fatigue and resultant stimulus-instability, enough trials were given to insure learning: every S made R_+ on over 20 per cent of his trials.

C. Results and Discussion

1. *Tests of Theorem 7: Response-Alternations*

For each individual was computed the ratio of his actual alternations in response to his total opportunities for alternations after the first R_+. The mean for each group was computed, weighting each subject proportionally to the number of trials upon which his ratio was based (cf. 6, p. 66; 7, p. 21).

Arranging the groups in order with respect to relative stimulus-stability also arranges the groups in order with respect to mean frequency of alternations (see Table 2, Column 3). The order of the five groups is that predicted from the theory, a result significant beyond the 1 per cent level of confidence.[4]

TABLE 2
GROUP MEANS PERTINENT TO THEOREMS 7 AND 8

Groups from relatively stable to least stable stimulus conditions	No. of Ss	Mean ratio of actual alternations to maximum alternations possible	Mean ratio of actual length of longest R_+ series to longest R_+ series possible
1—Most stable	32	.12	.76
2—No key-response	12	.34	.46
3—No "breathing"	12	.42	.45
4—Neither	12	.43	.39
5—Neither, plus other varying stimuli	12	.51	.29

[4]There are 120 permutations of five things taken five at a time. Only one of these is the particular order demanded by the theory. Therefore by "chance," one time in 120 five groups would be arranged with respect to some characteristic in the one particular order specified by the theory.

Means may be determined largely by a few deviant individuals. Therefore the means of groups can fit a theory even when the majority of individuals give results at variance with the theory. To check upon this possibility, a Chi-square test was run. This test shows that the number of individuals with relatively few or many alternations is closely related to the degree of stimulus-stability. (The χ^2_c is significant far beyond the 1 per cent level of confidence; see Table 3.) In the group with greatest stimulus-sta-

TABLE 3
RELATIONSHIP BETWEEN STABILITY OF STIMULUS CONDITIONS AND FREEDOM FROM ALTERNATIONS

Percentage of trials after first R_+ on which an alternation occurred		Degree of stimulus-stability: Least stable (Groups 4 & 5)	Intermediate (Groups 2 & 3)	Most stable (Group 1)	Total
0-15%	f_o	1	4	23	28
	f_c	(8.40)	(8.40)	(11.20)	
16-45	f_o	8	11	8	27
	f_c	(8.10)	(8.10)	(10.80)	
46-80	f_o	15	9	1	25
	f_c	(7.50)	(7.50)	(10.00)	
Totals		24	24	32	80

$\chi^2_c = 34.0$; 4 degrees of freedom; $p < .01$.

bility, half of the individuals had no alternations whatsoever after their first R_+. Such records were made by only 8 per cent of the subjects having less stimulus-stability.

2. *Tests of Theorem 8: Longest R_+ Series*

In any specified number of trials following the first R_+, individuals under progressively more stable stimulus-conditions should have, on the average, progressively more R_+'s in their longest R_+ series. Data would not necessarily accord with this theorem merely because they accorded with Theorem 7.[5]

[5]Individuals with relatively few alternations do not necessarily have longer consecutive series of R_+'s than do individuals with more alternations. For example, six *S*s might have 1, 2, 3, 4, 5, and 6 alternations respectively in 10 trials following their first R_+. Each of these six *S*s could have the same number of R_+'s in his longest series and have the same percentage of his trials comprised of his longest series: Each might have only two R_+'s in his longest series, or each might have three R_+'s, or each might have four R_+'s in his longest series during the 10 trials—despite the fact that their numbers of alternations were very different in those 10

To test Theorem 8, the number of R_+'s in each individual's longest unbroken series was divided by his total number of trials after and including his first R_+ (as is demanded by assumptions in the deduction of the theorem). Means for the five groups were computed, weighting individuals proportionally to the number of trials on which their ratios were based.

Each group with relatively more stable stimulus-conditions averaged more R_+'s in their longest series than any group with less stable stimulus-conditions. (See Table 2, Column 4.) The group with the most stable stimulus-conditions had single R_+ series which averaged 76 per cent as long as was possible (i.e., on the average, 76 per cent of the total trials following each individual's first R_+ was comprised of a single unbroken R_+ Series). Groups with progressively less stable stimulus-conditions fell progressively far below this. The order of the five groups is exactly that predicted by Theorem 8, a result significant beyond the 1 per cent level.[6]

Here again, the data for individuals also is that expected on the basis of Guthrie's theory. The greater the degree of stimulus-stability imposed by the experimental design, the greater the number of individuals with relatively long R_+ series. Chi-square is significant far beyond the 1 per cent level of confidence (see Table 4).

3. *The Rôle of Internal Stimuli in Conditioning*

For Group 1 vs. Groups 2 and 3, the experimentally controlled conditions differed only in the extent to which various *internal* stimuli were stabilized. However, the resultant response-sequences differed greatly. For example, Group 1 had only about one-third as many alternations as either Group 2 or Group 3. These data demonstrate that internal stimuli (emotional, proprioceptive, and others) can be extremely important determiners of the individual's response, with their rôle not being limited to a motivational one.

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trials. Data which accorded with Theorem 7 could be at wide variance with Theorem 8.

[6]The *relative* sizes of the means (not their absolute sizes nor the size of the differences) is the proper test of the theory, since it is only the former result about which the theory made predictions. However, as a matter of interest the statistical significance of the differences in means follow. (*a*) For number of alternations, using a *t*-test (6, p. 72ff.), $p < .01$ for Group 1 vs. each of the other groups; $p \cong .02$ for Group 2 vs. Group 5; $p \cong .07$ for Group 3 vs. Group 5; $p > .10$ for Groups 2 or 3 vs. Group 4, and for Group 2 vs. Group 3. (*b*) For percentage of trials comprised of an unbroken R_+ series, $p < .01$ for Group 1 vs. Group 4, and for Group 1 vs. Group 5; $p = .02$ for Group 1 vs. Group 3; $p = .03$ for Group 1 vs. Group 2; $p > .10$ for the other comparisons, with $SE_{diff} = \sqrt{\frac{P_T Q_T}{N_1} + \frac{P_T Q_T}{N_2}}$

TABLE 4
RELATIONSHIP BETWEEN STIMULUS-STABILITY AND LENGTH OF LONGEST R_+ SERIES

Percentage of trials after first R_+ which was comprised of longest R_+ series		Degree of stimulus-stability: Least stable (Groups 4 & 5)	Intermediate (Groups 2 & 3)	Most stable (Group 1)	Total
60-100%	f_o	4	4	27	35
	f_c	(10.50)	(10.50)	(14.00)	
35- 89	f_o	6	13	3	22
	f_c	(6.60)	(6.60)	(8.80)	
10- 34	f_o	14	7	2	23
	f_c	(6.90)	(6.90)	(9.20)	
Totals		24	24	32	80

$\chi^2_c = 37.7$; 4 degrees of freedom; $p < .01$.

Some additional empirical evidence is afforded by notes made during the experimental sessions. These notes indicate many instances on which a change in eyelid response coincided with a change in *S*'s internal stimulus-patterns.[7] The following are illustrative.

One subject, arms on the table, made 11 successive R_+'s. He then moved his arms from the table and crossed them; on the next trial, R_+ did not occur. Before the next trial, he placed his arms on the table as before, and R_+ again was made. Another *S* made a long series of R_+'s. He then coughed, and changed his position to such an extent that the beam of light from the eyelid-lever no longer fell on the camera. The *S* seemed very disturbed by this, offered rather profuse apologies, and announced he was going to hold his breath for a while so he would not cough again. For the next few trials, no R_+ occurred.

Another *S* was extraordinarily restless throughout the experiment, sighed often, shifted his position almost every trial, twice so greatly that the lever became untaped from his eyelid. (This is the only case where that happened.) At the end of the session, *S* reported that he had had a recurrent and intense cramp in his leg during the experiment. This *S* had an alternation on 73 per cent of his trials, almost twice as many as any other member of that experimental group and six times as many as the mean for that group.

The preceding observations, while far from conclusive, are offered for their heuristic value. Such observations of "incidental" stimuli may furnish helpful additional bases for predicting individual responses.

[7]Since at the time of the experiment, *E* was only casually interested in this phase of the problem, the notes are suggestive but lack the completeness necessary for statistical analysis.

4. *Interpretation of the Failure of Responses to Appear Sometimes After Having Once Been Evoked*

Often a response fails to appear after having been evoked on previous trials under similar circumstances. These failures of response are accounted for in different ways by Hull and Guthrie.

Hull would say the response-failures are due partly to (*a*) variations in the stimulus-patterns present on various trials, (*b*) differences in the ${}_{S}\overline{E}_{R}$ arising from increments in the various inhibitory potentials during and between trials, (*c*) "spontaneous" oscillation of ${}_{S}E_{R}$, and (*d*) the gradualness with which each *S-R* connection is strengthened with repeated reinforcements (3, 4, 5).

Guthrie postulates that each *S-R* connection is established with full strength after the response once has been made in the presence of those stimuli (1, 2). According to this theory, the failures of a new response to appear after having been evoked on some previous trial are due solely to variations in the on-trial stimuli and to unlearning between trials of some (or all) of the desired *S-R* connections. This unlearning, in turn, is a function of on-trial and between-trial similarity: The greater the similarity of the on-trial and the between-trial stimuli, the greater the number of desired *S-R* connections which can be unlearned between trials.[8]

To account for the data of this experiment, we need assume neither gradual strengthening of *S-R* connections nor the existence of ${}_{S}O_{R}$. The Guthrien explanation fits the data nicely: The less the on-trial stimuli differed from trial to trial and the less they resembled the between-trial stimuli, the more sharply curtailed were the response-failures and the less gradual were the P_{R+} increments. Response-failures virtually disappeared when variations in on-trial stimuli and similarity of on-trial and between-trial stimuli were minimal. No longer did P_{R+} increase gradually. Instead P_{R+} increased suddenly after the first R_{+} to a near 100 per cent level.

Clearly gradualness of these P_{R+} increments is related closely to the necessity for forming different *S-R* connections on different trials and to the opportunities for unlearning desired *S-R* connections between trials.

These data raise some doubts whether ${}_{S}O_{R}$ exists and whether any *S-R* connection gains strength gradually. Perhaps all occasions which seem to involve ${}_{S}O_{R}$ and gradual strengthening of *S-R* connections involve instead

[8]Increasing the extent to which between-trial stimuli duplicate on-trial stimuli increases also the number of on-trial stimuli the subject must learn to ignore before R_{+} can appear with high consistency on the various trials. As a consequence of this too, *S-R* connections may *appear* to be gradually strengthened.

fluctuations in on-trial stimuli and duplication of on-trial and between-trial stimuli.

Do we have any clear evidence that ${}_{S}O_{R}$ exists or that an *S-R* connection ever gains strength gradually?

D. Summary

From Guthrie's postulates of one-trial learning, one-trial unlearning, postremity, and the postulate that response-probability is proportional to the percentage of all present stimuli which are cues for R_{+}, the following theorems have been formally deduced: In progressively more stable situations, there will be on the average (*a*) progressively fewer alternations in response, and (*b*) progressively higher percentages of the trials comprised of a single R_{+} series. The limiting case is for perfectly stable situations, in which should occur jumpwise curves containing no alternations in response and indefinitely long R_{+} sequences.

To test these theorems, conditioned eyelid responses were established for five groups of *S*s under progressively more stable stimulus-conditions. That is, each group had progressively less variability in their on-trial stimuli and progressively less similarity of their on-trial and between-trial stimuli.

As stimulus-stability increased, the proportion of trials comprised of a single R_{+} series increased and the number of response-alternations decreased to the point where half the *S*s had no alternations whatsoever after their first R_{+}. Since the data for the five groups fit both theorems, they support the validity of the four Guthrien postulates from which the theorems were deduced.

The data also suggest: (*a*) On-trial responses are a function of many stimuli besides "the" *CS* and *US*. (*b*) Internal stimuli (emotional, proprioceptive, and others) are important determiners of the individual's responses. Were these "incidental" stimuli noted more closely, possibly we would not need to postulate ${}_{S}O_{R}$ nor gradual strengthening of any *S-R* connection. (*c*) Relative similarity of complex situations can be estimated from an *a priori* analysis of the situations, with such estimations furnishing an adequate basis for prediction of responses. Inherent in all theories of behavior is a need for such estimations. (*d*) Increasing response-probability may be due rarely, or even never, to some reinforced *S-R* connection gradually gaining strength. Instead the gradualness with which P_{R+} sometimes increases may be due largely to a gradually increasing number of stimuli becoming cues for the desired responses.

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