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ACQUISITION OF S–R CONNECTIONS: A TEST OF HULL'S AND GUTHRIE'S THEORIES

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Is an S–R connection gradually strengthened by repeated reinforcements? Or is an S–R connection established suddenly, in an all-or-none fashion?

Hull has given us the most complete statement of the view that the connections are gradually strengthened. His most recent theory states (**10**, p. 5): "Whenever an effector activity is closely associated with a stimulus afferent impulse or trace (*s*) and the conjunction is closely associated with the rapid diminution in the motivation stimulus (S_D or S_G), there will result an increment to a tendency for that stimulus to evoke that response" (Postulate 3). "If the reinforcements follow each other at evenly distributed intervals, everything else constant, the resulting habit will increase in strength as a positive growth function of the number of trials" (Postulate 4).

Guthrie has offered the alternative suggestion that an S–R connection is fully established in one pairing of the stimuli and the new response (cf. **5**, p. 419 f.; **6**, p. 98).

The experiment here reported attempts to test the validity of these alternative proposals.

Conditions Required by Hull's Theory

Although S–R connections cannot be observed directly, their nature can be inferred under certain circumstances implicit in the two theories. In Hull's theory, we can infer the nature of S–R if we ascertain the value of $_SE_R$ and the corresponding $_SH_R$. To determine these values and how they vary with *N*, the following conditions are necessitated by Hull's 1952 postulates. They were necessitated also by his 1943 theory, though for slightly different reasons.

Requirement 1: Stimulus-variability from trial to trial must be negligible.—Meeting this condition stabilizes *V*, desirable in terms of Postulate 8.[2] More important, it minimizes variations in afferent interaction, so $_SE_R$ has a relatively determinable magnitude.

Hull assumes *all* afferent impulses (*s*'s) present at any time interact and partially change each other (into $\check{s}$'s), thus changing $_SE_R$ (Postulate 11). Unfortunately,

[1] This paper is based upon parts of a doctoral dissertation presented to the faculty of Yale University. The author is now with San Diego State College.

[2] To reduce printing costs, Hull's postulates are referred to by number only. Complete statements are available elsewhere (**10**, pp. 5–14).

he does not specify the empirical conditions under which greater or lesser changes from afferent interaction occur. Suppose the stimuli on Trials 4, 5, and 6 differ somewhat. Will the stimuli on Trial 5 interact to give $\check{s}$'s more like the $\check{s}$'s of Trial 4 than those resulting from interaction of stimuli present on Trial 6? Or less? Or the same? At present we cannot answer those questions without circular assumptions. Consequently, when different stimuli are present on various trials, we cannot predict either the amount or direction in which the resultant $_{S}E_{R}$'s will differ from trial to trial.

Requirement 2: Stimuli present on trials (S_t) *should be absent between trials.*—Meeting this condition avoids confounding reinforced and nonreinforced $S_t - R_+$ sequences. It also minimizes I_{R+} and $_{S_t}I_{R+}$, which should be negligible since they reduce $_{S_t}E_{R+}$ by unknown amounts (Postulate 9A and Corollary 9).

Although the theory suggests conditions under which the various inhibitory potentials increase, it does not enable us to predict *how much* they increase under various conditions, but only *that* they increase. Consequently, we cannot predict the nature of the response-evocation curve when appreciable amounts of the inhibitory potentials are present.

Any results can be postdicted when Requirements 1 and 2 are not fulfilled, by assigning (legitimately) different values for various trials to the inhibitory potentials and to the effects of afferent interaction. Postdictions under such circumstances afford no check on the theory. This means that to test Postulates 3, 4, or 8, as the theory currently stands, the various inhibitory potentials and the changes in afferent interaction must be negligible.

Requirement 3: Ample intertrial time must be allowed for dissipation of I_R.—This follows from the above considerations and from Postulate 9B.

Requirement 4: The response must involve minimal work.—This will further reduce $_{S_t}I_{R+}$, since $_{S_t}I_{R+}$ is a function in part of the amount of I_{R+} present with the on-trial stimuli (Corollary 9) and the amount of I_{R+} present is hypothesized as being an increasing function of the amount of work involved in making R_+ (Corollary 10).

Requirement 5: Drive and incentive must be as nearly constant as possible.—Unmeasured variations in these factors would cause unpredictable fluctuations in $_{S}E_{R}$ (Postulate 8 and Corollary 12), and thus preclude determining the nature of $_{S_t}H_{R+}$.

Requirement 6: The original level of $_{S_t}E_{R_+}$ *should be zero.*—This is desirable since otherwise the original level of $_{S_t}E_{R+}$, which partially determines the shape of the learning curves, cannot be established.

Conditions Required by Guthrie's Theory

Nearly the same conditions necessitated by Hull's theory are needed to test Guthrie's theorem predicting jumpwise learning curves for stable conditions (Theorem 6, **16**, p. 358). A stable situation was defined as "a set of stimulus-patterns . . . having the following characteristics—(*a*) all stimuli present on Trial X are present on all succeeding trials, (*b*) none of the stimuli present on Trial X is present between trials, (*c*) none absent from Trial X is added on succeeding trials" (**16**, p. 357). Trial X is the first trial on which R_+ occurs; R_+ is the response *E* wishes to cue to the experimental stimulus-patterns.

Therefore, to test Theorem 6, Requirements 1, 2, and either 3 or 4 must be met. Either the response must involve little work or the time between trials must permit dissipation of fatigue products, since (by Guthrie's theory) the accumulation of fatigue products creates new, varying stimulus-patterns.

Method

A conditioning procedure was used, R_+ being a partial or complete blink or wink; US, an air-puff by the fall of 100–130 mm. of mercury, magnetically released; one of the main CS's, a damped buzz. The buzz began about .45 sec.

before the puff and ended about .09 sec. after onset of the puff.

Subjects and Apparatus

All *S*s were male undergraduates of Yale University. None had studied conditioning. In the main experiment, 32 *S*s participated, and 25 others in preliminary tests. The apparatus is substantially the same as that previously described and photographed (**13**). A continuously recording camera designed by W. R. Miles was used to photograph the eyelid responses (magnified 3.5 times) and the onset and offset of all stimuli.

Conditions

Requirement 1.—To maintain more stable and unique on-trial stimuli, the following procedures were introduced. Throughout each trial, *S* depressed a telegraph key with each hand. The keys were depressed "as soon as possible" after a signal, "with a firm smooth motion," held down "with constant pressure" until a buzz terminated, and then released. Each *S* practiced making the response in the particular way sketched. Depression of both keys activated the buzz; contact was broken if either key was released slightly, thus affording a check on the relative constancy of pressure. A stiff spring was used in the keys, so the response involved muscles of the arms and shoulders as well as of the hands.

At the start of each trial, *S* breathed in rhythm to *E*'s saying "Ready, inhale, exhale, inhale, hold." The words were spoken slowly, with about 2 sec. between the first four, 1½ to 3 sec. between the last two. On the last "inhale," *S* inhaled "as deeply as possible," and in response to "hold," held his breath and depressed the keys.

Besides stabilizing the key-response, this routine should have increased the similarity of the on-trial stimuli arising from the diaphragm, intercostals, and other muscles of the chest, shoulders, and upper arms.

To minimize autonomic changes and concomitant changes in internal stimuli, *S* must have either a constant excitement or a constant calmness throughout the experiment. The latter is more feasible. To reduce the apprehension with which many *S*s start (but usually do not finish) their first experimental session, *E* chatted with *S*, answered his questions, and appeared, at least, to allay his many fears about possible shocks, snakes, and other noxious stimuli. Instructions were given slowly, in a conversational manner. The *S* practiced all parts of his routine and was assured he was doing fine. The experiment began only when *S* appeared comfortable and confident he could do what was expected of him. To mitigate increasing "nervousness" about the need for finishing the session, *S* was asked to allow an hour before he signed up; on arrival, he was told that although it might seem longer, we would stop after no more than 45 min. No *S* was run during his examination week nor immediately before any class test.

Changes from increasing fatigue and also in proprioception were reduced by keeping the session as short as was consistent with other considerations, having the intertrial interval long enough to permit *S* to relax between trials and yet short enough to avoid impatience (as evinced by *S*'s reports and almost no signs of restlessness), adjusting *S*'s chair so he sat in his normal position with his back supported, and arranging the keys so each *S* could rest his arms comfortably on the table between trials.

If *S* speculates about the nature of the experiment, forming first one hypothesis and then another, and adopting first one set and then another toward blinking, this unstabilizes a segment of the on-trial stimulus-patterns. Therefore, *S* was told that this was a study of "individual differences in reaction time." No *S* questioned the stated purpose; most *S*s expressed interest in the results of their "reaction-time test."

A soundproof room was used; all necessary movements by *E* were highly routinized; except for these, *E* was nearly soundless; *S*'s head was surrounded by a box, sharply limiting his visual field; *S* was requested not to talk during the experiment (unless fatigued or something seemed to be going wrong).

Requirement 2.—The following sets of stimuli were present on trials but absent between trials: (*a*) Most of the proprioceptive and tactual stimuli from the key-response; (*b*) stimuli from inhaling deeply and holding one's breath; (*c*) various visual stimuli (*S* closed his eyes between trials); (*d*) the buzz.

Requirement 3.—Intertrial intervals were 45, 50, 55 . . . 75 sec., arranged in randomized order. Though the time needed for I_R to dissipate is not known, two lines of evidence suggest this was ample: (*a*) Probably few fatigue products were present immediately after the response; negligible amounts should remain after blood circulates past the effectors for about a minute. (*b*) Calvin (**3**) showed that with 20 sec. between trials, probability of the eyelid response was 54% and with 3.33 sec., 20% after equal conditioning trials; these data suggest the I_R dissipation curve is leveling off at 20 sec.

Requirement 4.—The eyelid reaction entailed minimal work.

Requirement 5.—Pressure of the puff was adjusted to each *S*'s sensitivity and elicited practically a full wink on each trial. The puff was directed to the middle of *S*'s eyeball, since puffs to various parts of the eyeball are probably more alike than ones to the eyeball and ones to the cornea, and it is easier to hit the eyeball consistently than to hit the cornea consistently. The *S*'s chin was supported on a chin rest; his head was strapped snugly against a forehead rest; and, during the trials, he looked at a cross, thus further stabilizing the US (and possibly *D* and *K*).

Requirement 6.—To each preliminary *S*, all CS's were presented 30 times without the puff. Photographs also were made of five preliminary tests for each *S* in the main experiment. None of these *S*s showed any trace of a wink to any of the CS's.[3]

Number of Trials

The mean number of trials was 17.1, a range of 9 to 25. The number was kept small to avoid increasing fatigue or restlessness, but was sufficient to be certain learning had occurred. Each *S* made at least five R_+'s (mean, 12.1) and at least 32% of his total trials contained R_+ (mean, 72%).[4]

Criteria for R_+

After studying preliminary records of voluntary blinks and other incidental movements occurring when the cross was fixated for 5 sec., the following criteria were selected to differentiate between CR's and voluntary or incidental responses. An eyelid response was counted as R_+ only when it involved a closing-opening sequence, an amplitude of at least 1½ mm., occurred after onset of the buzz but before the puff, and had a record line of rapid ascent and peakedness. The R_+'s with relatively short and long latency were compared with respect to shape, amplitude, frequency, and changes in amplitude and frequency as a function of number of preceding trials. The two groups of responses were substantially the same: short-latency responses behaved a bit more like what one expects of CR's than did the relatively longer latency responses, but with no statistically significant differences (**15**). Therefore, all R_+'s are considered together in this study.[5]

Other *E*s have included responses occurring after onset of the puff (**4**, **11**, **12**), ones of less than 1½ mm. amplitude (**4**, **7**, **14**), flat humps (**7**), gradual tetanic lowering without raising and gradual tetanic raising of the lid (**2**). Though these may well have been CR's too, incidental responses (from head movements, shifts in gaze, etc.) sometimes give highly similar records. Therefore, they were not counted as R_+ in this study. Since our criteria are more definite and stringent than what appear to be usual, it is unlikely any greater stability of R_+ here is due to "flexibility" in what was counted.

Results and Discussion

Tests of Hull's Theory

Amplitude of response.—According to Hull's theory, $_SE_R$ progressively increases with the number of S–R reinforcements (Postulates 3, 4, and 8). Therefore, if amplitude of eyelid responses is similar to that of the PGR or is positively correlated to any degree with $_SE_R$,[6] amplitude of these

[3] The various CS's were tested on *S*s run before the 57 *S*s, and were made so weak it seemed unlikely they would evoke any eyelid responses. However, two people (originally intended as *S*s) blinked within a half-second after a CS, and so were dropped.

[4] For an extinction experiment, both the number of R_+'s per *S* and the percentage of trials containing R_+ had to be equated for members of this group and for members of four other groups who learned under different conditions. This precluded having the same number of trials for all *S*s.

[5] When using procedures similar to the present one, other *E*s also have included as CR's responses which appeared within a few milliseconds after onset of the part of the CS sequence corresponding to my buzz, or even a few milliseconds before its onset (cf. **1**).

[6] Literally and precisely construed, no amplitudes (except those of the PGR) can be interpreted within the framework of Hull's theory. Postulate 15 of the 1943 version anchors $_SE_R$ to amplitude only of responses mediated by the autonomic nervous system, while Postulate 15 of the 1952 version limits the anchorage to amplitude of the Tarchanoff galvanic skin reaction. Strictly speaking, the present amplitude data are irrelevant to Hull's theory. However, the data are relevant to Hull's theory as used by many investigators. Even Hull himself used mean amplitude of the lid reaction as an indicator of $_S\bar{E}_R$ (**8**, p. 291, p. 306) and in discussions made it parallel to amplitude of PGR (**8**, p. 291f). Similarly Hull used the amplitude of line-drawing responses as a reflector of $_SE_R$ (**8**, p. 306 f.), and presented curves for the amplitude of bar-pressing responses "to illustrate the oscillation of reaction potential ($_SE_R$)" (**8**, p. 305).

responses should increase with N (Postulate 15)—providing ${}_SO_R$, I_R, and ${}_SI_R$ increase with N no more rapidly than does ${}_SE_R$, the stimuli present on successive trials are substantially the same, and D, V, and K remain substantially constant. It will be recalled that special effort was made to meet these assumptions. (We have no control over ${}_SO_R$, of course.)

To test this hypothesis, we calculated the mean amplitude of each S's responses during the various quarters of his trials beginning with the first trial he made R_+.[7] The mean for each quarter was compared with every other quarter, making six comparisons for each S. In no case is the percentage of Ss whose data accord with the theory significantly more than 50% by usual statistical standards (see Table 1).

TABLE 1

RELATIVE AMPLITUDE OF RESPONSES IN VARIOUS QUARTERS OF EACH S'S TRIAL BEGINNING WITH HIS FIRST R_+

In Accord with Theory		At Variance with Theory		p**
Quarters Compared*	Per Cent of Ss	Quarters Compared	Per Cent of Ss	Sig. of Diff. from 50%
1st<2nd	65.62%	1st>2nd	34.38%	.04
1st<3rd	56.25	1st>3rd	43.75	.24
1st<4th	65.62	1st>4th	34.38	.04
2nd<3rd	59.37	2nd>3rd	40.63	.15
2nd<4th	68.75	2nd>4th	31.25	.02
3rd<4th	62.50	3rd>4th	37.50	.08

* No two quarters for any S had the same mean amplitude.
** One-tailed test of significance.

A second analysis is summarized in Table 2. For 6 of 32 Ss, amplitude behaved as would be expected, the mean of each quarter of trials becoming progressively larger. For no S was the curve completely reversed. By "chance," 1.33 Ss would fall in each of those categories. Although again in the right direction, throughout the distribution the deviations from "chance" are small and not statistically significant.

For 25 of the 32 Ss, the first R_+ was smaller than the last R_+. This is significantly more than half of the Ss ($p<.01$).

Probability of response.—In the last two revisions of his theory, Hull did not formally anchor ${}_SE_R$ or ${}_SH_R$ to P_R. Presumably he was working on a new equation for this, but had not arrived at a satisfactory one. Clearly he intended to keep the concept, since his last book abounds with theorems, analyses, and theoretical graphs using P_{R+} as an indicator of ${}_SE_R$ and ${}_S\bar{E}_R$.

From Hull's discussions (**9, 10**) and

[7] Hull postulates that ${}_SH_R$ gradually increases with N even while the correlated ${}_SE_R$ minus ${}_SO_R$ and I_R is less than ${}_SL_R$. That is, ${}_SH_{R+}$ is said to gradually increase with N even before R_+ once has been made in the presence of those Ss. Maybe it does. However, none of the observable correlates of ${}_SH_R$ will show any change with N before R_+ has once appeared. Obviously amplitude, latency, and probability of the never-yet-made R_+ cannot reflect the presence of the postulated increases in ${}_SH_R$. Equally obviously they cannot reflect the absence of the postulated increases in ${}_SH_R$ until the R once has been made. It would be nice to avoid confounding those data which can have no bearing on Hull's theory with the data which might have some bearing. Therefore, in this study, the trials *before* the first R_+'s were grouped together, and the trials from the first R_+ on were considered separately.

For each S, these trials were divided into quarters. Precisely how this was done can be illustrated best by an example. Suppose S made no R_+ for three trials and then had 21 more trials. Each quarter after and including his first R_+ contains $5\frac{1}{4}$ trials. The total amplitude of his first quarter is the sum of amplitudes for Trials 4 to 8 inclusive plus $\frac{1}{4}$ the amplitude of R_+ on Trial 9. Similarly the total amplitude for the second quarter is the sum of $\frac{3}{4}$ the amplitude of R_+ on Trial 9, plus those from Trials 10 through 13, plus $\frac{1}{2}$ the amplitude of R_+ on Trial 14. The total amplitudes for the third and fourth quarters are computed in the same way. Dividing each total by $5\frac{1}{4}$ gives the mean amplitude per quarter for this S. Mean amplitudes are calculated from those of the largest R_+ on each trial.

TABLE 2

RELATIONSHIP BETWEEN AMPLITUDE AND N FOR INDIVIDUALS

Measure	Number of Times Mean Amplitude of an Earlier Quarter Was Smaller Than That of Some Later Quarter*						
	0	1	2	3	4	5	6
Number of Ss	0	4	4	6	5	7	6
Number expected by "chance"	1.33	4.00	6.67	8.00	6.67	4.00	1.33

$\chi_c^2 = 3.82$ (combining categories 0–2 and 4–6); 2 df; $p = .16$

* No two quarters had the same mean amplitude.

Postulates 3 and 4, we would expect that under the present conditions S would make R_+ with a frequency gradually increasing with N.

This expectation is not confirmed. Each of 16 Ss invariably made R_+ after once doing so. The data for the other 16 Ss also offer little evidence that $_SE_R$ gradually increases with N. For these Ss too, the on-trial stimuli almost invariably evoked R_+ after it appeared once. In other words, most Ss had horizontal "learning curves" with a dip perhaps in one place. Table 3 presents a comparison of each quarter with every other quarter of an S's trials *following* his first R_+.[8] For no S was P_{R+} progressively larger from quarter to quarter. Only six Ss had data resembling a progressive increase. The nature of these curves can be seen from Table 4. Each has a shape quite different from the others.

Tests of Guthrie's Theory

Incidence of jumpwise curves.—In stable situations, an S who has once made a new response should make that response on every subsequent trial, regardless of the past frequency of other responses (Theorem 6). A stable situation is so defined that stimuli can be dropped from trial to trial, but new stimuli cannot be added nor can on-trial stimuli be present between trials, without unstabilizing the stimulus-series.

In progressively more unstable situations, the curves will deviate from a jumpwise character to a correspondingly greater extent. The complete rationale of this proposition is given in Theorems 7 and 8 (**16**, p. 359 f.).

In this experiment, stimulus-stability was high, but not complete. Hence we should predict from the theory that not all Ss will have jumpwise curves. However, the majority of individual curves should closely approximate a jumpwise character. If they do not, it is probable the theory is invalid.

Of the 32 Ss, 16 had perfect jump-

TABLE 3

RELATIVE P_{R+} IN VARIOUS QUARTERS OF EACH S'S TRIALS AFTER HIS FIRST R_+

In Accord with Theory		At Variance with Theory	
Quarters Compared	Per Cent of Ss	Quarters Compared	Per Cent of Ss
1st<2nd	15.62%	1st≧2nd	84.38%
1st<3rd	18.75	1st≧3rd	81.25
1st<4th	21.87	1st≧4th	78.13
2nd<3rd	15.62	2nd≧3rd	84.38
2nd<4th	21.88	2nd≧4th	78.12
3rd<4th	18.75	3rd≧4th	81.25

[8] Including the trial on which R_+ first occurred would have worked against Hull's theory, since then the first quarter would have had to contain at least one R_+.

wise curves. Most of the others had curves closely approximating that: 10 *Ss* had only one lapse; 4 had two lapses; 2 had three or four.

Predictions of individual responses for each trial.—Whatever response an *S* made on the immediately preceding trial was predicted for the next trial. This particular way of using the principle of postremity assumes that the stimuli present at the time for which the response is being predicted were present on some former occasion when the response now predicted had been evoked and were not subsequently present during an incompatible response.

There is a far more precise way to use the principle of postremity and Guthrie's other postulates: Note as many as possible of the stimuli now present and what response was underway when each of those stimulus-patterns was last present. Then predict as the response whatever response the majority of the current stimuli last accompanied, whether or not that was the response made on the immediately preceding trial. This method of prediction, through a more refined use of the theory, would tend to vitiate this experiment, for it quite naturally would raise a question concerning subjectivity. We therefore followed

TABLE 4

CHANGES IN P_{R+} FROM FIRST TO LAST QUARTER FOR *Ss* MOST NEARLY FITTING HULLIAN EXPECTATIONS

Patterns Resembling a Progressive Increase of P_{R+} with N	Number of *Ss* with Each Pattern
1st = 2nd = 3rd < 4th	1
1st = 2nd < 3rd = 4th	1
1st < 2nd = 3rd = 4th	2
1st < 2nd < 3rd = 4th	2
1st < 2nd < 3rd < 4th	0
1st ≦ 2nd ≦ 3rd ≦ 4th	6 Total

TABLE 5

ACCURACY OF PREDICTIONS FROM GUTHRIE'S THEORY FOR INDIVIDUAL RESPONSES

Predicted Correctly	Number of *Ss*	p*
90–96%	15	<.006 for each *S*
80–89	9	<.01 for 8 *Ss*, .03 for 1 *S*
70–79	5	<.03 for 3 *Ss*, <.05 for 1 *S*, .07 for 1 *S*
60–69	2	.15 for 1 *S*, .21 for 1 *S*
50–59	1	.50 for 1 *S*

* One-tailed test of significance, using the binomial expansion.

the rather crude, but objective, method sketched above.

The percentage of individual responses predicted correctly from Guthrie's theory and the statistical significance for each *S* is summarized in Table 5. For almost all *Ss*, the predictions were highly accurate: over 90% of the predictions were correct for 15 of the 32 *Ss*; over 75% for 26 *Ss*.[9] For 28 of the 32 *Ss*, the accuracy was significant beyond the 5% confidence level; for each of 23, beyond the 1% level.

The accuracy of predictions for the group as a whole was evaluated by two statistical tests: (*a*) Of the total predictions made, 84.6% were correct. (The unweighted mean is 84.7%.) With an N of 32, this deviation from 50% is significant beyond the 1% level. (*b*) Two-thirds or more of the predictions were correct for each of 30 *Ss*. If no systematic factor were operating, this would happen in our group of 32 *Ss* far less than 1 time in 1000.

Accuracy of predictions in various portions of trials.—In a perfectly stable

[9] For one *S*, only 50% of the predictions were correct. This *S* shifted his position frequently during the trials and twice moved so greatly he loosened the lever attached to his eyelid. After the experiment, he reported that he had had an intense recurrent cramp in his leg. Probably it would have been legitimate to drop this *S* who so clearly did not meet the requirements for either theory.

TABLE 6

ACCURACY OF PREDICTIONS FOR EACH QUARTER OF TRIALS AFTER THE FIRST R_+

Quarter of Trials	Responses Predicted Correctly*
First	83.33%
Second	84.33
Third	91.79
Fourth	91.79

* The percentages weight each individual equally. None of the differences between these percentages is statistically significant, each t test giving a $p > .15$, by one-tailed tests of significance.

series of situations, the accuracy of predictions such as those made above should remain constant from one portion of trials to another.

In an unstable series, predictions of this sort should become increasingly accurate as the series progressed. With an unstable series of situations and an increased number of occasions some specified response has been made, more stimuli will have accompanied that response. It thus becomes increasingly likely that a high proportion of any situation will be comprised of stimuli previously present when the response was made. Therefore, when predictions are made by the particular method used in this experiment, their accuracy should increase as the series progresses. (If predictions were made by the more refined use of postremity sketched in the last section, the accuracy should remain constant from one portion of trials to another, even in a very unstable series of situations.)

Since the situations were nearly stable in this experiment, accuracy of our predictions should increase only slightly from the beginning to the end of the series. Table 6 presents the pertinent data.

Further Data

In Fig. 1 and 2 the data for response amplitude and frequency are plotted in the usual way. The shape of these curves strikingly resembles many reported by other investigators. A wealth of experimental data shows that under many sorts of learning conditions, the desired response is made with an increasing frequency and mean amplitude for *groups* of *Ss*.

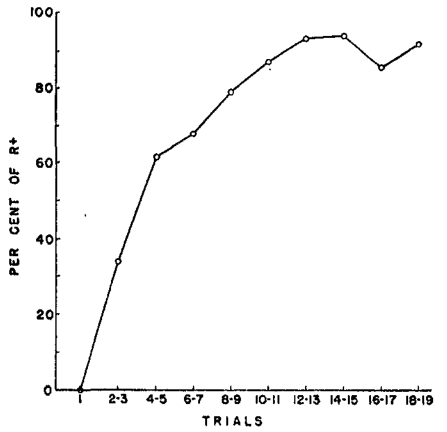

FIG. 1. Probability of R_+ for *Ss* grouped. For the first six points, $N = 31$ *Ss*; for the last four points, $N = 30.0$, 25.5, 17.5, and 12.5, respectively, which is all *Ss* having that many trials or more. The *S* with only nine trials was dropped, so that the first six points would be strictly comparable.

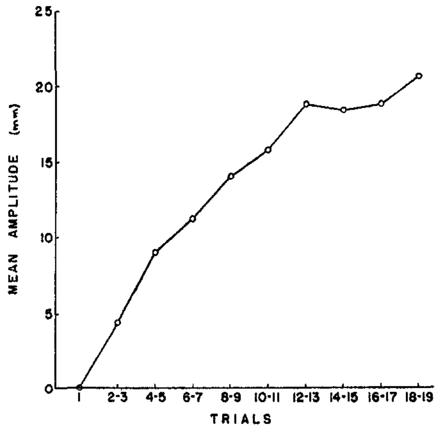

FIG. 2. Mean amplitude of R_+ for *Ss* grouped For the first six points, $N = 31$ *Ss*; for the last four points, $N = 30.0$, 25.5, 17.5, and 12.5, respectively.

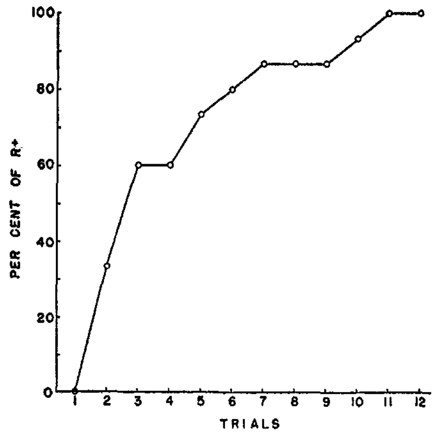

FIG. 3. Probability of R_+ for 15 *S*s each of whom had jumpwise curves

Mainly upon such facts we have based the idea that S–R connections are gradually strengthened with repeated evocations.

But do these facts necessarily mean that an S–R connection is becoming gradually stronger? Although such curves would be expected if there is gradual strengthening of an S–R connection, *they also would be expected if there is not.* This is a matter we sometimes have overlooked.

Suppose different individuals learn at different times. Even if each individual learns suddenly, when the data are grouped the resultant curve will show a progressive increase in P_{R+}. Figure 3 illustrates this. It is a composite for 15 *S*s, each of whom invariably made R_+ after it was once evoked. The group has a gradually increasing P_{R+} strongly resembling that of Fig. 1, but no individual had any gradual increase in P_{R+}. To conclude from such curves that any S–R connection is being gradually strengthened might be a trifle rash.

A similar phenomenon occurs with amplitude. Much of the apparent increase in mean amplitude with N is not due to R_+ becoming larger. Rather, the apparent increase is largely due to different *S*s making their first R_+ on different trials. Figure 4 factors out the effect of this; Fig. 2 does not. Figure 4 shows far less increase in mean amplitude with N.

Under two other conditions such curves as those of Fig. 1 and 2 would result, regardless of whether an S–R connection is gradually strengthened or is established suddenly with full strength. If (*a*) there is much stimulus-variability from one learning occasion to the next or from one test occasion to the next, or if (*b*) there is high similarity between the on-trial stimuli and the between-trial stimuli, the learning curves will increase only gradually.

The first instance confounds the acquisition of several different $_SE_R$'s. The greater the stimulus-variability, the greater the variety of stimulus-patterns which must be established as cues for R_+. The smaller the proportion of this total population of stimuli which is present on any specified learning trial, the greater the number of trials needed to establish any specified part of them as cues for R_+. By either Hull's or Guthrie's theory, this will

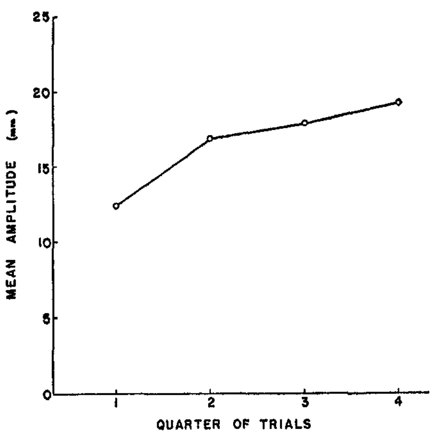

FIG. 4. Mean amplitude of R_+ per quarter of trials following the first R_+

cause probability of R_+ to increase only gradually with N.

We turn now to the second possibility. In terms of Hull's theory, when stimuli which are cues for R_+ subsequently are present when R_+ is made but not reinforced, those S–R connections are weakened. In terms of Guthrie's theory, when stimuli which are cues for R_+ subsequently are present in conjunction with other stimuli which evoke a response incompatible with R_+, those S–R_+ connections are broken. By either theory, the frequency of R_+ would be reduced by the opportunities for unlearning which arise when on-trial stimuli are present between trials; thus P_{R+} would increase more gradually.

The above circumstances would tend to cause also a gradual increase in mean amplitude, since (as generally computed) mean amplitude is a function in part of the number of R_+'s made in each block of trials.

The data of this experiment suggest these three conditions (and not gradual strengthening of S–R connections) may be responsible for the fact that often mean amplitude and frequency gradually increase with N.

Interpretation from Hull's Theory

Hull has used probability and amplitude of striped muscle responses as evidence of $_SE_R$. An individual's $_SE_R$ is postulated as progressively increasing with N in a stable situation. But for almost no individual in this experiment did either amplitude or probability progressively increase with N. These data do not support the theory.

Neither, in a sense, do they refute the theory. In the same sense, no data could. For these or any other conditions, one can adjust at least five factors (none of which is anchored to any observable aspect of the person or environment) and thus postdict any results whatsoever.

The data of this experiment cannot be reconciled with Hull's theory by remembering that Requirements 1–5 were met imperfectly. To the extent those conditions were not met, the resultant curves (according to Hull's theory) would be irregularly depressed. But it is an opposite characteristic of the curves which needs to be explained: The curves are far more regular and show fewer evidences of gradual S–R strengthening than expected. It will be recalled, for example, that half of the *S*s have jumpwise probability curves, and the other half very nearly so.

We can account for the present data by the method mentioned above. Without violating the theory, we can try different values for $_SL_R$ and D, and for the constants in Equations 4 and 29, having various values high for some *S*s and low for others. We also can assume, for some of an *S*'s trials, that $_SO_R$ is very high; on others of his trials, very low. By judiciously selecting values for these unanchored symbolic constructs, after careful study of the obtained results, each individual's probability and amplitude data can be postdicted. But by this technique any curve can be postdicted equally well regardless of its shape and *regardless of the conditions under which it was obtained.* (Prediction obviously is not to be expected if we accept Postulate 17 of Hull's most recent theory.)

This experiment deals with one response only. The learning of other S–R connections may be different. Perhaps some S–R connections are established gradually, while S–R's of this type are established suddenly. This remains a logical possibility. However, the S–R connections studied here are of a type previously deemed among the most likely to be gradually acquired.

Summary

An eyelid conditioning procedure was used with 32 human *S*s. Stimulus-variability, similarity of on-trial and off-trial stimuli, and other sources of Hull's various inhibitory potentials were minimized to an unusual extent. The conditions were peculiarly favorable for obtaining smoothly increasing curves.

However, when one largely eliminates those factors which, according to Hull's theory, cause sporadic dips in $_SE_R$, one eliminates also virtually all evidence suggesting a *gradual* increase in $_SE_R$ with N.

For individuals in a stable situation, P_{R+} jumps from 0 to 100% or very nearly 100% for almost all *Ss*. When we compare the number of R_+'s in each quarter of an *S*'s trials after his first R_+, in only 16–22% of the comparisons does a later quarter contain more R_+'s than some earlier quarter.

The amplitude data are closer to expectations based on the assumption of a gradually increasing $_SE_R$. An *S*'s first R_+ generally was smaller than his last. However, beginning with his first R_+ and comparing each quarter of an *S*'s trials with every other quarter, we find increases from earlier to later quarters in only 59–66% of the comparisons (not significantly more than 50%).

Predictions of individual responses based largely upon Gurthrie's principle of postremity had over 90% accuracy for 15 of the 32 *Ss*, over 75% accuracy for 26 *Ss*. Accuracy for most *Ss* and also for the group as a whole was statistically significant beyond the 1% level.

The data suggest that when P_{R+} does increase gradually with N, this may not be due to gradual strengthening of any S–R connection. Rather, the gradual increase may occur because (*a*) R_+ must be cued to a variety of situations and not all of the S–R connections are being established on any one trial, (*b*) some unlearning is occurring between test trials, with subsequent relearning being necessitated, and/or (*c*) different *Ss* learn at different times and their results are being considered together.

It appears quite possible that no S–R is gradually strengthened with repeated reinforcements. Perhaps every S–R is established suddenly, in an all-or-none fashion.

References

1. Beck, L. H. Conditioning and the coordination of movements. *J. gen. Psychol.*, 1939, **20**, 375–397.
2. Bernstein, A. L. Temporal factors in the formation of conditioned eyelid reactions in human subjects. *J. gen. Psychol.*, 1934, **10**, 173–197.
3. Calvin, J. S. Decremental factors in conditioned-response learning. Unpublished doctor's dissertation, Yale Univ., 1939.
4. Cole, L. E. A comparison of the factors of practice and knowledge of experimental procedures in conditioning the eyelid response of human subjects. *J. gen. Psychol.*, 1939, **20**, 349–373.
5. Guthrie, E. R. Conditioning as a principle of learning. *Psychol. Rev.*, 1930, **37**, 412–428.
6. Guthrie, E. R. *The psychology of learning.* New York: Harper, 1935.
7. Hilgard, E. R. Conditioned eyelid reaction to a light stimulus based on the reflex wink to sound. *Psychol. Monogr.*, 1931, **41**, No. 1 (Whole No. 184).
8. Hull, C. L. *Principles of behavior.* New York: Appleton-Century, 1943.
9. Hull, C. L. *Essentials of behavior.* New Haven: Yale Univ. Press, 1951.
10. Hull, C. L. *A behavior system.* New Haven: Yale Univ. Press, 1952.
11. Marquis, D. G., & Porter, J. M. Differential characteristics of conditioned eyelid responses established by reflex reinforcement. *J. exp. Psychol.*, 1939, **24**, 347–364.
12. Miller, J., & Cole, L. E. The influence of a "voluntary" reaction upon the development and the extinction of the conditioned eyelid reaction. *J. genet. Psychol.*, 1936, **48**, 405–439.
13. Porter, J. P. Temporal factors in experimental extinction. Unpublished doctor's dissertation, Yale Univ., 1936.
14. Switzer, S. A. Backward conditioning of the lid reflex. *J. exp. Psychol.*, 1930, **13**, 76–97.
15. Voeks, V. W. Stimulus stability and the acquisition of S–R connections. Unpublished doctor's dissertation, Yale Univ., 1947.
16. Voeks, V. W. Formalization and clarification of a theory of learning. *J. Psychol.*, 1950, **30**, 341–363.

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