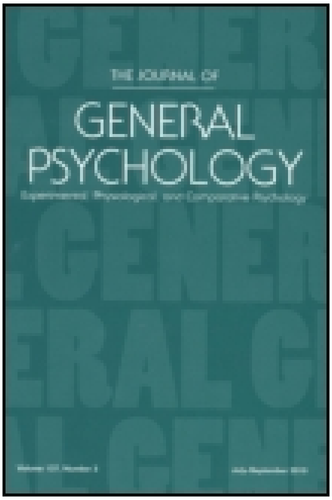

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THE MEASUREMENT OF REACTIVE INHIBITION IN HUMANS*

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A. INTRODUCTION

The analysis of individual differences in learning requires that we achieve as pure and as reliable measures as possible of intersubject variability on the basic components of performance. The question of what these basic components are is both theoretical and empirical. Hull's system, for example, analyzes performance in terms of hypothetical variables such as habit strength, drive, reactive inhibition, conditioned inhibition, etc. (3, 4). Hull also postulated individual differences in each of these factors. Thus, different subjects could conceivably show identical performances on a particular learning task, but for quite different reasons, since performance is the resultant of a number of different factors which can take different values for different individuals. In another type of learning task the relative importance of the various factors might be quite different and then the performances of these same subjects might not be at all alike. Such is one of the major problems of delineating the dimensionality or structure of individual differences in "learning ability."

The present study is concerned with the measurement of one of the above-mentioned factors: viz., reactive inhibition, which will be designated hereafter by Hull's symbol I_R. Hull defined I_R as follows: "Whenever any reaction is evoked in an organism there is left a condition or state which acts as a primary negative motivation in that it has an innate capacity to produce a cessation of the activity which produced the state" (3, p. 278).

Demonstrations of the hypothesized role of I_R in learning and performance, as well as the assessment of individual differences in I_R, have been made largely by means of the pursuit rotor. The evidence on the effects of distribution of practice and on reminiscence have been interpreted largely in terms of I_R. As a means of measuring individual differences in I_R, however, the pursuit rotor has some pronounced shortcomings. First of all, the task obviously involves a considerable amount of learning; and, therefore, in terms of Hull's system,

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it must be heavily loaded on the habit strength ($_SH_R$) factor. Secondly, the measurement of the reminiscence effect, from which the amount of I_R is inferred, is based on only a very small sample of prerest and postrest performance, usually totaling not more than 20 or 30 seconds. Thus, highly reliable measurements are rarely, if ever, achieved. Furthermore, since pursuit rotor performance soon becomes asymptotic, obtaining repeated measures of the amount of reminiscence on the same subjects becomes quite problematic. Finally, it is likely that the factor of neural consolidation (not postulated by Hull) operates during the rest period and would enter into the magnitude of the reminiscence effect. Actually, a strong case can be made for questioning whether the reminiscence effect reflects the magnitude of I_R much at all (1).

A means of measuring I_R (or, more exactly, the effects of I_R) is needed that does not involve the disadvantages found in the pursuit rotor method. Variance due to the learning or habit strength factor and to the neural consolidation factor should be minimized and there must remain the possibility of obtaining a sufficiently large sample of behavior from the individual subject, as well as repeated measurements, to permit the achievement of adequate reliability for the study of individual differences.

Hull's formulation of the independent variables of which I_R is a function itself suggests a simple method of measuring I_R and of testing whether these measures do in fact behave in accord with Hull's conception of I_R. According to Hull, the amount of I_R generated is a function of (*a*) the amount of *work* involved in each response, (*b*) the *number* of responses, and (*c*) the *rate* of responding. The method of the present study allows the experimental manipulation of each of these independent variables. The purpose of the study is to determine whether the technique yields reliable measures and whether these measures can properly be identified as reflecting I_R, in terms of some of the characteristics of I_R that can be deduced from Hull's formulation.

B. Method

1. *Apparatus*

The apparatus consisted essentially of three heavy-duty Morse telegraph keys mounted on a circular board in such a way that the knobs of the keys formed the points of an equilateral triangle. The knobs were 1.25 inches in diameter and the centers of the knobs were 6 inches apart. The black knobs protruded through a flat-gray plywood panel, which covered the rest of the apparatus, so that all that was visible to the subject (S) were the knobs—and a light, to be described shortly. Each key was attached to an electric counter which would register the number of taps on the key. When depressed, the keys also turned on a light which the *S* could see through a lens-covered aperture placed behind the keys; this light served as an indicator that the keys were being tapped sufficiently hard to make electrical contact.

The amount of physical *work* required to depress each key is, of course, a product of the *force* required and the *distance* through which the key must move. All three keys were adjusted to move through the same distance: viz., .1 inch. The tension of the keys was adjusted so that either one or two of them required a pressure of 1.5 ounces while the others required 21 ounces (in some experiments the keys were weighted 1.5, 1.5, 21 and in others they were 1.5, 21, 21). Thus, the "heavy" key always required 14 times more work than the "light" keys. Consequently, since I_R is a function of the amount of work involved in making a response, it should build up more rapidly to the response of tapping the heavy key than to the light key.

The apparatus was placed on a table at a height such that the *S* standing in front of the table could comfortably touch the keys without having to stoop. The three knobs were in the horizontal plane. To eliminate most of the noise created by tapping the keys, the interior of the apparatus was lined with foam rubber.

2. *Procedure*

Six experiments were performed in all, each with somewhat different procedures, the specifics of which can be described most efficiently in connection with the results of each experiment. To be described here are only those aspects of the procedure that are common to all the experiments.

*S*s were never informed of the true purpose or rationale of the experiment. They were simply told it was a means of assessing their "flexibility" or their ability to avoid a rigid pattern in the order of tapping the keys; they were urged to try and make their order of tapping the keys as nearly *random* as possible.

Each trial lasted from four to 10 minutes of continuous tapping, and all *S*s were given at least three trials, separated by rest periods of at least 10 minutes. The circular apparatus was rotated to a different position on every trial, so that the odd weighted key was always in a different position. A preliminary investigation revealed that the position of the keys was an insignificant factor so long as (*a*) the apparatus was rotated from trial to trial and there were at least three trials, and (*b*) the "sides" of the triangle formed by the knobs were never parallel to any edge of the table.

In five experiments *S*s were required to keep time with a metronome while tapping the keys; in the sixth experiment *E* made no mention of *rate* of tapping, the metronome was eliminated, and *S*s tapped at their own rates.

3. *Subjects*

The *S*s in the first three experiments were 12 university students; the same 12 *S*s participated in each of the three experimental conditions.

The *S*s in Experiments 4, 5, and 6 were young adults who were patients diagnosed as neurotic in a rehabilitation center. The *N*s in Experiments 4, 5, and 6 were nine, nine, and 15, respectively.

C. Results and Discussion

1. *Experiments 1, 2, and 3*

The first three experiments used one heavy key (21 ounces) and two light keys (1.5 ounces). Four trials were given in all cases, with 60-minute rest periods between trials.

In Experiment 1 each trial lasted five minutes and *S*s were required to tap the keys at random in time with a metronome at the rate of 208 taps per minute.

In Experiment 2 each trial lasted 10 minutes, with a tapping rate of 104 per minute. Thus, the same number of taps was required as in Experiment 1, but they were distributed over more time, which should allow for greater dissipation of I_R within trials.

In Experiment 3 the trials lasted 10 minutes, at a tapping rate of 208 per minute, but *S*s alternated 10 seconds of tapping with 10 seconds of rest. This distributed practice should allow considerable dissipation of I_R within trials.

The *S*s' total numbers of taps on each key on each trial were the measurements subjected to an analysis of variance. According to Hullian theory, the difference between the number of taps on the heavy key and the mean of the two light keys should reflect the amount of I_R built up during each trial; since the response of tapping the heavy key involves more work than either of two light keys, the *S*'s tapping of the heavy key should become inhibited relatively quickly and his responses should gravitate to the light keys.

The analysis of the results of these three experiments supports the following conclusions: (*a*) In all experiments there were significantly ($p < .001$) fewer taps on the heavy key than on either of the two light keys, which did not differ significantly in number of taps. (*b*) In all experiments there were significant individual differences on the proportion of the total taps that were made on the heavy key. The mean reliability of this measure, as determined by the intraclass correlation over all four trials, was .75. (*c*) The slower *rate* of tapping (Experiment 2) and the distribution of tapping interspersed with 10-second rest pauses (Experiment 3) both resulted in significantly ($p < .05$)

less decrease in tapping of the heavy key than did the massed tapping at a fast rate (Experiment 1).

Thus, this key-tapping task behaves very much in accord with expectations from Hull's conception of I_R: the response requiring more *work* becomes more inhibited than responses requiring less work; decreasing the *rate* of responding decreases the inhibitory effect; and providing intermittent rest pauses results in decreased inhibitory effect, presumably because I_R rapidly dissipates during rest, as it should, according to Hull's formulation.

It should also be noted that there is little room in this simple task for learning or the growth of ${}_SH_R$; it is practically all performance. *S*s show no appreciable improvement once they get into the rhythm of the metronome, which takes only a few seconds. After that, if anything, performance tends to deteriorate slightly throughout the course of a single trial—*S*s begin to skip beats or they will momentarily lag behind the click of the metronome, so that the total number of taps during a trial is almost always somewhat less than the number of metronome beats.

The performances of six of the *S*s in Experiment 1 were recorded on a kymograph which permitted a count of the number of taps on each key within every 10-second period throughout the four-minute trial. These data revealed that the proportion of taps on the heavy key was the same as for the light keys at first but gradually decreased throughout the trial.

*S*s' performances did not appear to differ appreciably from trial to trial, which suggests that reliability could be boosted to almost any desired level by means of repeated measurements.

2. *Experiments 4, 5, and 6*

An attempt was made in these experiments to improve the reliability of the measurement of individual differences in I_R and to test other implications of the hypothesized characteristics of I_R.

It was thought that greater amounts of I_R could be generated by using two heavy keys and one light key; this was done in all three of these experiments. The experiments also have in common that three trials, each of four-minute duration, were used, separated by 10-minute rest periods.

Experiment 4 involved tapping in time with the metronome at the rate of 160 taps per minute. The analysis of variance of the results showed that the number of taps on the light key was significantly ($p < .001$) greater than for either of the heavy keys, which did not differ significantly.

For comparative purposes a convenient index of the amount of I_R may be obtained from the formula: [(300 × number of taps on the light key)/total taps] — 100. Experiment 4 yields a mean index of I_R of 5.57. The reliability of individual differences on this measure, as determined by the intraclass correlation over three trials, was .89.

The analysis of variance also revealed significant ($p < .01$) differences between *S*s in total number of taps over all keys. This was not found in the first three experiments which used only one heavy key and two light keys. This finding suggests that the task of tapping, when there are two heavy keys, generates enough inhibition that it shows up, not only in decreased tapping of the heavy keys, but also as generalized inhibition to the task as a whole. Brief, involuntary rest pauses, momentary lagging behind the metronome, and the like—all are reflections of inhibition—resulted in the fact that, on the average, *S*s made only 92 per cent of the required number of taps. Also, *S*s differed reliably ($r = .79$) in this generalized inhibitory tendency as measured by the percentage of the required number of taps.

In Experiment 5 it was attempted simultaneously to *decrease* the amount of overall inhibition, so that *S*s would come closer to making the required number of total taps over all keys, and, at the same time, to *increase* the amount of I_R as it is reflected in the difference between the number of taps on the light and heavy keys.

*S*s were instructed to start tapping only a designated *pair* of keys in a random fashion until they began to feel tired, whereupon they were to change to a different pair of keys, and so on. This procedure introduces the *S*'s own subjective judgment of fatigue or inhibition as one determinant of his performance. It was hypothesized that *S*s would tend to spend more time tapping light-heavy pairs than heavy-heavy pairs, so that consequently the proportion of taps on the light key would be even greater than in Experiment 4. Also, it was hypothesized that this procedure, which encouraged *S*s to vary their pattern of tapping whenever they subjectively experienced I_R, would result in less overall inhibition of the whole task.

The results bore out both of these expectations. The index of I_R was 8.90 as compared with 5.57 in the previous experiment; and *S*s, on the average, made 96 per cent of the required number of total taps as compared with 92 per cent in the previous experiment. Since *S*s began each trial by tapping a different pair of keys, the intercorrelations of the index of I_R from trial to trial cannot provide a proper estimate of reliability. That is, the three different trials cannot be regarded as truly equivalent forms of the task in this procedure, but it is possible to make some inference regarding reliability by comparing the variance due to the Keys × Subjects interaction in Experiment 5 with the corresponding variance in Experiment 4. This comparison reveals that the variability among *S*s on the index of I_R is more than four times greater in Experiment 5 than in Experiment 4; at the same time, *S*s in Experiment 5 were more consistent from trial to trial in the overall number of taps. These facts taken together suggest that the index of I_R as derived from Experiment 5 has considerably higher reliability than was found in Experiment 4 and is probably well above .90.

There is also the possibility that in this procedure, since *S*s were instructed to change keys according to their subjective experience of fatigue, other factors than I_R might have entered into their performance. The degree of correlation between the index of I_R as obtained from the procedures in Experiments 4 and 5 remains to be determined; correlations must also be obtained between these and other measures of I_R if we are to be sure that we are not dealing merely with task-specific variability, however reliable it might be.

Experiment 6 was intended to test the hypothesis that less inhibition would build up when *S*s are allowed to tap at their own, self-determined rates. According to this view, the rate of tapping would be determined, at least in part, by the rate at which the *S* builds up and dissipates I_R. The *S* should tap at a rate that maintains a balance between the build-up and the dissipation of I_R. In terms of Hull's theory, one other factor would also determine spontaneous tapping rate: viz., drive (*D*). The greater the *D* or motivation of the *S*, the faster the tapping rate. The *D* factor should not, however, affect the index of I_R, which is based, not on tapping rate *per se,* but on the relative frequency of taps on the light and heavy keys. Keeping the tapping rate relatively constant by means of the metronome should also minimize the effect of *D*.

In Experiment 6 the procedure was the same as in Experiment 4, except that the metronome was removed and no mention was made of *rate* of tapping. If the *S* asked how fast he should tap, he was simply told "at whatever rate feels comfortable to you." Precautions were taken to prevent the *S* from hearing the tapping of other *S*s, so that every *S* would enter the laboratory without any preconceptions of how fast he should tap.

The results of Experiment 6 show a mean index of I_R of only 3.54, which is less than that produced by any of the procedures with the metronome. In fact, the difference between the number of taps on the light and heavy keys did not even approach significance at the .05 level, while in all the other experiments this difference was significant beyond the .001 level. It may be concluded that I_R did not build up to any appreciable degree under self-paced tapping.

The mean overall number of taps was not appreciably different from the previous experiments; it constituted 94 per cent of the number that would be required by a metronome rate of 160 per minute. But there was much greater variability among *S*s in total taps and these individual differences had a reliability of .97, as determined by the intraclass correlation over three trials. Thus, rate of tapping under these conditions appears to be an extremely stable characteristic of individuals. As was pointed out earlier, this characteristic, according to Hullian theory, would not be thought of as unidimensional but would be a joint function of two factors—drive (D) and inhibitory potential (I_R). Applying the various procedures of key tapping described in this paper to the same group of *S*s should make possible the independent measurement of individual differences in both D and I_R.

In conclusion, it should be noted that tapping speed probably reflects some quite basic and stable trait of "personal tempo" rather than merely a superficial aspect of behavior governed largely by the *S*'s momentary interpretation of the instructions or his perception of the purpose of the task. The more fundamental nature of "personal tempo" as measured by tapping speed is indicated by the fact that a strong hereditary tendency has been found in tapping speed, preferred metronome speed, and the like (2, pp. 238-239). Monozygotic twins resemble each other in tapping rate more than do dizygotic twins, and parent-child and sibling concordances are all significantly greater than they are among unrelated persons. The present Hullian analysis suggests that tapping rate is not a unidimensional trait but may be determined by both motivational and inhibitory factors. A dimensional analysis of tapping rate would therefore seem to be indicated as a necessary step in working out a genetic model for "personal tempo."

D. Summary

A method was devised for measuring individual differences in one factor in Hull's formulation of reaction potential: viz., reactive inhibition (I_R). The technique consisted essentially of having *S*s tap, in a random fashion at a rate set by a metronome, three Morse keys which were weighted differentially so as to require different amounts of work. The measure of I_R is based on the differential number of taps on the three keys within a specified time interval. This measure of I_R showed characteristics consistent with Hull's formulation of I_R: (*a*) it was greater under massed than under distributed practice, (*b*) it was greater under fast than under slow rates of tapping, and (*c*) it was least under self-paced tapping, which suggests that the spontaneous tapping rate is governed in part by the build-up and dissipation of I_R—self-paced tapping maintains a balance between the build-up and the dissipation

of I_R. The measure of I_R had satisfactory test-retest reliability (.75 to .90 under various conditions). The test-retest reliability of total number of taps under the self-paced condition over three four-minute trials was .97. The dimensional analysis of tapping rate as an indicator of a stable trait was discussed both in terms of Hullian theory, which postulates two dimensions—drive and inhibition—as determinants of tapping rate, and in terms of the genetic basis of "personal tempo."

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