"WARM-UP" IN PURSUIT ROTOR LEARNING AS A FUNCTION OF THE EXTINCTION OF CONDITIONED INHIBITION

BY

H. J. EYSENCK

Institute of Psychiatry (University of London), Maudsley Hospital (1)

1. Introduction

It is a well-known principle in science that measurement is possible and meaningful only in terms of a theory, or set of theories. In psychology there has been a curious bifurcation. Psychometrists have perfected the technique of psychological *measurement* to a considerable degree, but have neglected very largely the whole area of psychological *theory*. Experimental psychologists, particularly those in the field of learning theory, have been very active in the development and testing of *theories* but have tended to neglect the task of *measurement*. In doing so they have tried, as far as possible, to suppress the major source of variance in their data, namely, that concerned with individual differences. Only occasionally, as in the case of a littleknown paper by Hull (2), are individual differences permitted to emerge, but only as modifying constants in the learning equations. The writer has attempted in a series of papers (3, 4, 5, 6) to integrate learning and perceptual theory, on the one hand, and the field of individual differences and personality dimensions on the other. In testing some of the predictions made, it became apparent that certain of the theories basic to such measurement were, in fact, incorrect, and a number of experiments had to be carried out in order to settle the theoretical issues raised. The present paper is concerned with the description of some of these issues, and a brief account of the experiments conducted and results achieved.

This difficulty arose particularly with reference to the prediction made by the writer in terms of his general theory of extraversion-introversion (7) that *reminiscence effects would be stronger for extraverts than for introverts*. The experimental testing of this prediction depends very much on the existence of a quantitative measure of reminiscence, and this in turn can only be derived from a more general theory of this phenomenon. Such a theory exists (8, 9) but its direct application to our problem is prevented by effects, such as "warm-up", which do not form part of the theory. It became necessary, therefore, to investigate the theoretical import of these

additional phenomena in order to make possible the testing of our primary hypothesis. This investigation is reported in the present paper; with the knowledge gained in this set of experiments it became possible to submit our primary hypothesis to a proper experimental test which verified it at a high level of statistical significance (10). It is to be expected that similar difficulties will arise in relation to the measurement of other variables which play a part in the theories of experimental psychologists and which appear also to be relevant to psychologists interested in individual differences and the "structure of personality".

2. The Theory of "Warm-up" Decrement

The theoretical and experimental analysis of the curve of work was begun by Kraepelin (11) and his students around the turn of the century. Thorndike's (12) criticisms of these early concepts helped to clarify the situation. In more recent years, interest has shifted somewhat to the effect of rest pauses and to the experimental study of phenomena such as the so-called "warm-up" effect. This is defined as a sudden initial rise in performance after a rest, which is succeeded by more nearly level stretches of the work curve, or even by stretches showing a downward trend. The theoretical basis for this phenomenon is well conveyed in the term used; practice is supposed to be facilitated by mental attitudes, muscular postures, and the like, which are lost during rest, and which have to be reinstated during the first few seconds of practice before optimum performance is possible.

Learning theorists do not appear to have given much thought to the importance of the influence of warm-up effects on the curve of learning, although the work of Bell (13), and particularly Ammons (14) forced it upon their notice. Ammons specifically introduced the concept of D_{wu}, or warm-up decrement, into his system. It is defined in terms of the relationships shown in Figure 1, which is quoted from his work: - "At any trial D_{wu} will be the vertical difference between line B and the postrest performance curve where line B is higher. D_{wu} is thus essentially the inverse of Bell's idea of "warming-up"." The Bell-Ammons concept of warm-up decrement appears to be a necessary complement to the Hullian treatment of learning, which does not attempt to account for the sudden continued rise in performance after a rest period.

In our own work, the concept of warm-up decrement became of importance only because of its relevance to the measurement of another hypothetical construct, namely, that of reactive inhibition (15). In the Hullian theory, reactive inhibition is accumulated during massed practice and dissipates during a succeeding rest. If the rest is long enough to allow of complete

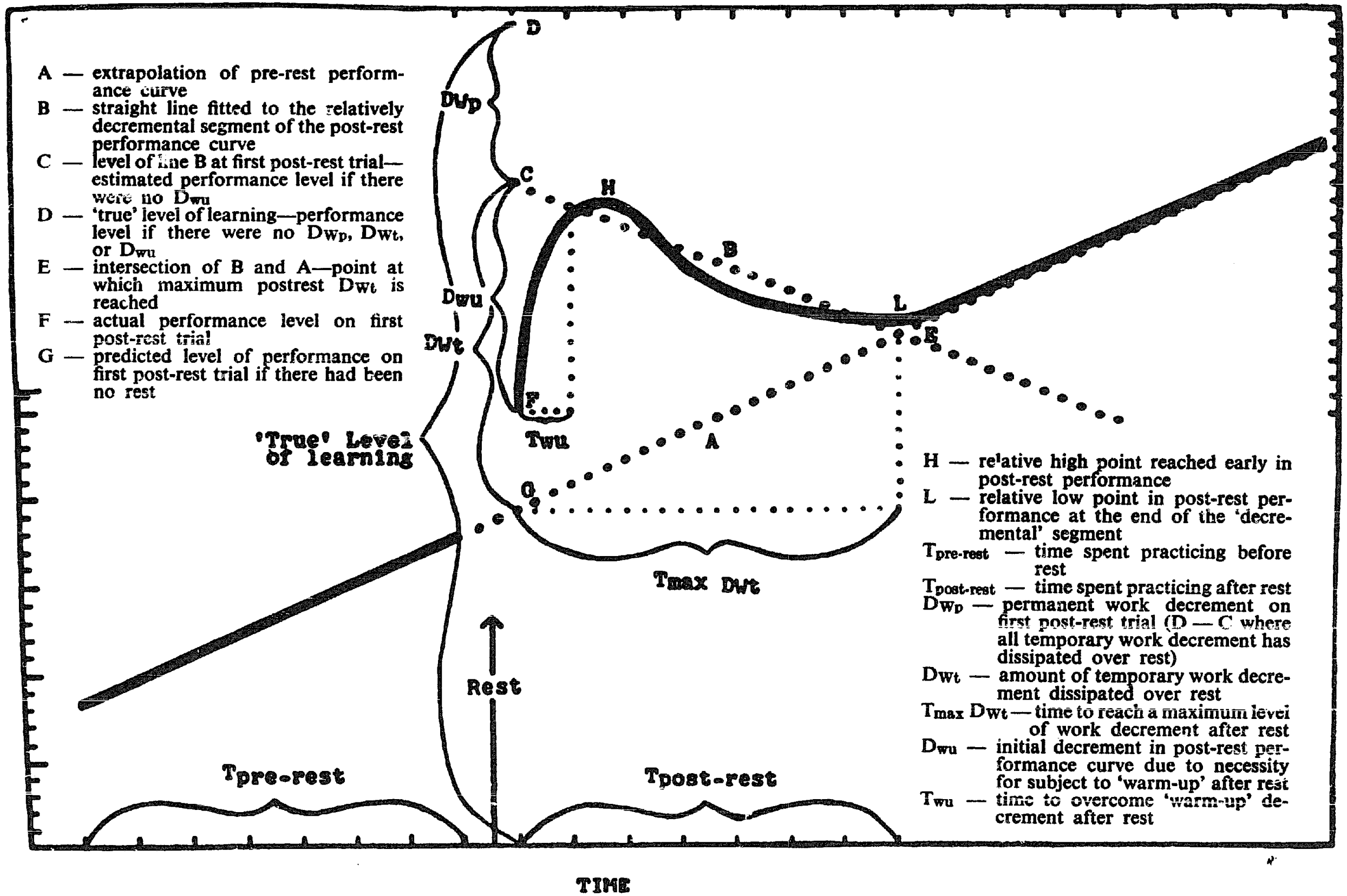

Fig. 1. Diagrammatical representation of Ammons' theory of warm-up effect. Quoted by permission of the *Psychological Review*.

dissipation, then the so-called reminiscence phenomenon, i.e., the increment in performance *immediately after* the rest as compared with performance *immediately before* the rest, will serve as an adequate measure of the amount of reactive inhibition accumulated. In Figure 1, therefore, the vertical distance between points G and F would be an adequate measure of reminiscence, and therefore of reactive inhibition (I_R). Ammons, however, argues that this way of measurement leaves out the rapid rise in performance between points F and H, which in his view is caused by warm-up. He would insist that this warm-up must be taken into account and he does so by defining the point C very much in the manner shown graphically in Figure 1. The distance between G and C is his estimate of reminiscence, and therefore of I_R, or, as he prefers to call it, temporary work decrement (D_{Wt}). These two methods of measuring reminiscence will be referred to as "uncorrected" and "corrected" respectively.

It will be seen that a decision as to the adequacy of Ammons's theory is quite vital if we wish to measure the amount of I_R accumulated at the point of rest. Not only would our estimates of reminiscence be very different if we substituted the vertical distance CG for the vertical distance FG; more important, the measurement of individual differences in reactive inhibition would become quite impossible, as individual performance curves are too irregular to allow us to estimate the position of point C with any kind of precision. The present paper, therefore, is concerned with a test of the hypothesis that the sudden rise in performance after rest is, in fact, a warm-up phenomenon.

There appears to be no doubt that warm-up does occur and that its influence can be manipulated experimentally. On nonsense syllable learning Irion (16) has shown that there is less warm-up if subjects retain their "set" by continuing to sit in front of the memory drum without change of posture, pronouncing the names of colours which are exhibited in the memory drum. Similar experiments by others (17, 18, 19, 20) have given results much in support of this general conclusion, and it seems quite impossible to doubt that part, at least, of the sudden rise in performance during the first few trials after a rest pause is due to warm-up (21). It is, however, difficult to believe that warm-up is responsible for the total rise which is, in fact, observed. One of the main reasons for thinking so lies in the time intervals concerned. In Ammons's diagram the rise from F to H takes place very quickly, i.e., within one or two practice trials. Considering the hypothesized nature of warm-up, i.e., the "shaking down" of the organism, both mentally and physically, into well-practiced attitudes and muscular sets, that is quite reasonable; we would expect the organism to be

"back on the job" within ten or twenty seconds. (The usual single trial lasts about ten seconds in pursuit rotor work from which most of the evidence on warm-up effects has come).

In actual fact, however, Ammons's diagram is misleading; the time intervals involved are usually much longer. The three curves appearing in the lower part of Figure 2 record an experiment on the pursuit rotor, conducted by the writer, in which three sets of thirty consecutive 10-second periods of practice are separated by two 10-minute rest pauses. (The records of 50 male University students are averaged in this figure) (22). It will be seen that the H-point in the curves following the rest pause is not reached until 110 seconds and 60 seconds respectively have elapsed. These times are far too long to make "warm-up" a likely hypothetical cause for the observed phenomena. It becomes necessary, therefore, to look for an alternative theory, and then to make deductions from this new hypothesis which would contradict deductions made from the "warm-up" hypothesis. In this way only would we be enabled to decide on the adequacy of Ammons's theory.

3. An Alternative Theory of Post-Rest Increment

The theory here proposed follows directly from Hull's postulates and the experimental and theoretical extension of that work made by Kimble (23, 24). Briefly stated, this theory treats I_R as a negative drive. I_R builds up during massed practice until it reaches a point where a brief involuntary rest pause is enforced. (This concept will be abbreviated I.R.P. in this paper to save space). During this I.R.P. some I_R dissipates, thus lowering the amount of inhibition present sufficiently to make resumption of practice possible. Practice then continues until I_R again reaches the point where another I.R.P. is enforced, and so on.

As I_R, being a negative drive, is reduced during these hypothetical I.R.P.'s, these act as a reinforcement for the prevailing state of affairs. The prevailing state of affairs being one of *not reacting*, we thus obtain the concept of a habit of not reacting which becomes conditioned the moment I_R reaches a sufficiently high concentration to enforce the rest periods which act as reinforcements. (This concentration will be referred to as the *critical level* of I_R.) This conditioned inhibition ($_SI_R$) does not dissipate during rest because it is a habit; it has therefore been symbolized by Ammons as *permanent* work decrement ($\mathbb{D}_{Wp}$). As Kimble has indicated, this permanent work decrement can be shown to exist and can be measured by comparing scores of a group of subjects who have done work in conditions of massed practice, followed by rest, with the scores made by a group of people who have done an equal amount of distributed practice. (The assumption here

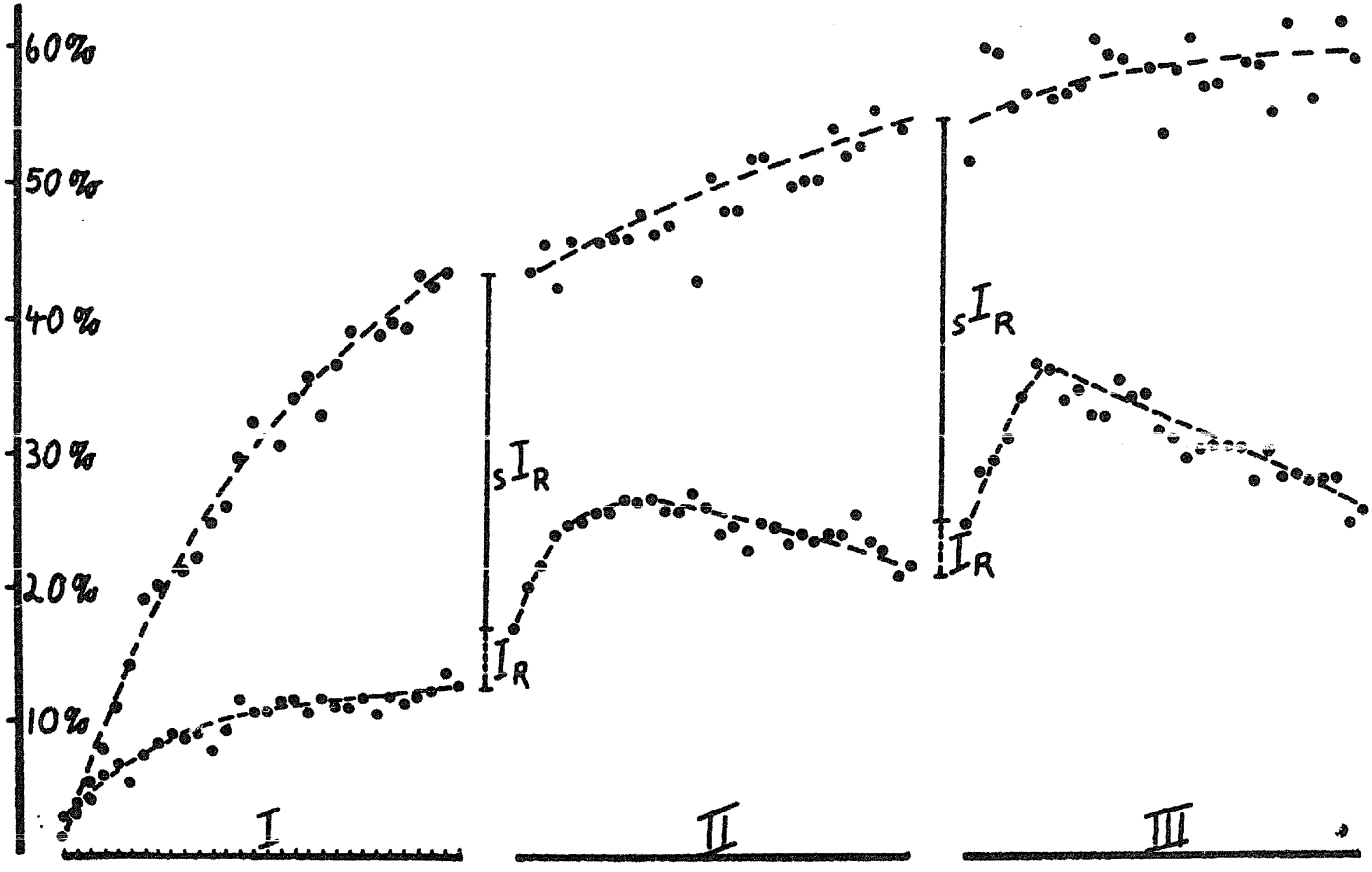

Fig. 2. Pursuit rotor performance as a function of massed practice (lower set of curves) and distributed practice (upper set of curves).

is that distributed practice is distributed sufficiently for I_R never to reach a concentration sufficiently high to enforce rest periods; before that happens, practice ceases and a rest is introduced by E which will allow all of the accumulated I_R to dissipate).

We are now in a position to put forward our own hypothesis regarding the sudden post-rest increment in performance. It is suggested that this rise in performance is due to the extinction of ${}_sI_R$ consequent upon the failure of ${}_sI_R$ to receive its appropriate reinforcement. This reinforcement, it will be remembered, consisted in the I.R.P.'s enforced by the high level reached by I_R. During the 10-minute rest, however, all of I_R has been dissipated, and consequently during the first minute or two after the rest pause I_R is accumulating again until it reaches its critical level. It is only when this point is reached, i.e., after a minute or two, that ${}_sI_R$ is reinforced. Until then, ${}_sI_R$, in accordance with learning theory, should extinguish in view of the fact that *no reinforcement is forthcoming.*

This theory of post-rest increment is similar in some ways to an hypothesis put forward by Denny, Frisby, and Weaver (25) to account for the fact that groups of subjects switching from massed to distributed practice finally achieve as high performances as groups of subjects starting with distributed practice and going on with distributed practice. Their explanation is as follows: "Theoretically, if one considers, as we do, that the unconditioned stimulus for the establishment of conditioned inhibition *is* the massing condition, then when massing (US) is omitted by introducing distributed practice the conditioned inhibition, like other conditioned responses, should undergo extinction." Our own phrasing would be slightly different. It would be to the effect that if one considers, as we do, that the unconditioned stimulus for the establishment of conditioned inhibition is the occurrence of rest pauses enforced by the accumulation of reactive inhibition due to massing, then the omission of these enforced rest pauses due to the dissipation of reactive inhibition during rest, causes conditioned inhibition, like other conditioned responses, to undergo extinction.

It is important to be quite clear about the sense in which our theory is an alternative to the Bell-Ammons warm-up hypothesis. It is not suggested that there is *no* warm-up after rest; what we are suggesting rather is that warm-up effects do not account for *all* the post-rest increment in performance which is observed, and that, in fact, the major part of this increment is due to the extinction of ${}_sI_R$. A complete theory of post-rest increment in performance thus requires three different concepts in addition to ordinary improvement through practice on the last pre-rest trial:

(1) *Reminiscence* or the increase from the last pre-rest trial to the first post-rest trial.
(2) *Warm-up* or the rapid rise in performance during the first few seconds of practice after rest. (Short-term increment, extending over 10–20" only).
(3) *Extinction increment*, caused by the extinction of ${}_sI_R$ producing a relatively long and rapid rise in post-rest performance (long-term increment; extending over 60–90").

It is important to keep these three phenomena distinct as their theoretical derivation and their experimental determination are quite different.

4. The Existence of ${}_sI_R$

Our theory for the explanation of post-rest increment in terms of the extinction of ${}_sI_R$ would clearly have very little value if any doubt existed about the development of ${}_sI_R$ as such. Ammons and Willig (26) report failure to find evidence for the existence of ${}_sI_R$, and quote several other writers in support. (27, 28, 29, 30, 31, 32, 33).

The experimental arrangements under which ${}_sI_R$ failed to be uncovered were not, however, entirely free from criticism. Where pursuit rotor learning was used, distributed practice often included uninterrupted periods of work of as long as one minute. There is ample room during a minute for both I_R and ${}_sI_R$ to arise (26). Massed practice periods have not always been strictly massed; in the work of Adams and Reynolds (34) for instance, 5 second rest pauses were incorporated in their massed practice periods. Other writers again failed to take into account the extinction hypothesis put forward by Denny, Frisby and Weaver (35). In other studies the Alphabet Printing Task was used. This is not as suitable, in our experience, as pursuit rotor learning in studies of this kind. The various parts of the task are much more practiced before the first experimental trial, than are the components of the pursuit rotor task; it is difficult to make trials as continuously massed; lastly, the different difficulty level of the task at different parts of the alphabet creates considerable disturbance. Figure 3 shows the mean scores of 50 male Ss on the Alphabet Printing Task, carried out in the manner described by Schucker et al. (36) There were 3 sessions divided by 10 minute rest pauses; each session consisted of 10 consecutive 30-second trials. There is no warm-up effect, but rather a drop in performance following the first trial in each session; there is no evidence of I_R or reminiscence, the rise in performance after the rest pauses not being statistically significant. In the absence of I_R, we would not expect any ${}_sI_R$ to arise, and failure to find evidence for the latter on this task cannot, therefore, be taken too seriously (37). Altogether, the considerable differences between Ss in pre-experimental familiarity

with the tasks make it difficult if not impossible, to generalize or interpret findings. As a pencil-and-paper measure of inhibition, the Tsai-Partington Numbers Test, as adapted by Ammons, appears much less open to objection (38, 39).

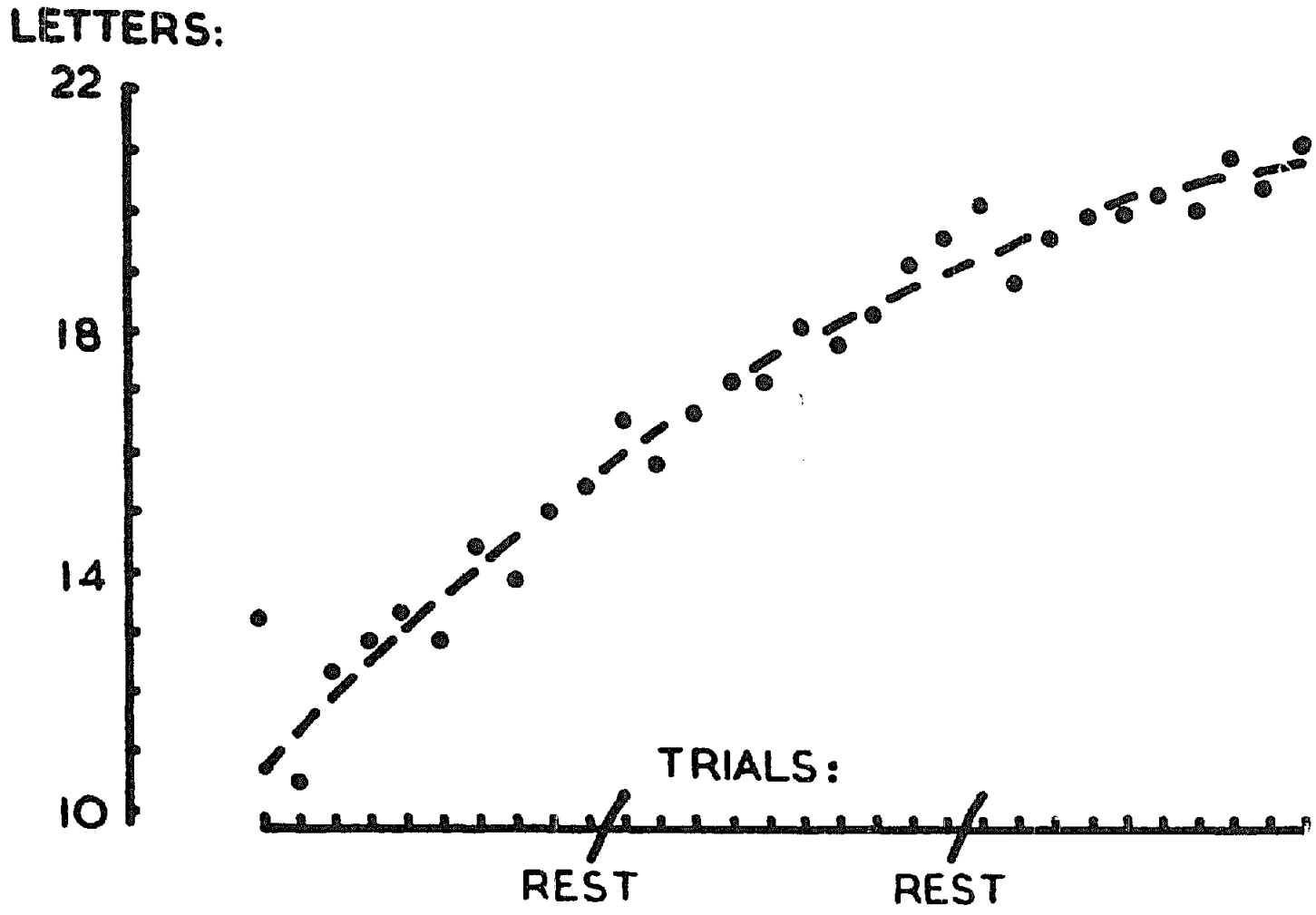

Fig. 3.
Improvement in the Alphabet Printing Task as a function of practice, showing failure of rest periods to produce reminiscence effects.

However valid these criticisms, it seemed more worth while to produce direct experimental evidence regarding the existence of ${}_{S}I_{R}$. Figure 2 shows the outcome of an experiment specially conducted for this purpose. The set of curves in the lower half of the figure has already been discussed. The set of curves in the upper half of the figure consists of 10 second trials separated by 30-second rest periods; records of 25 university students were averaged in order to obtain the results reported. Each 10-second period was preceded by $2\frac{1}{2}$ seconds practice during which no score was kept. This was done in order to make comparable the 10-second period of work in the D group (distributed practice) with corresponding 10-second periods of work in the M group (massed practice). In the M group each 10-second period would begin with the subject already in the middle of his task. If, in the D group, the subject were instructed to begin work at the beginning of the 10-second period, at least a second or more would be lost in his getting the stylus on to the turn-table, beginning to move it, etc. The $2\frac{1}{2}$-

second periods preceding each trial, while not scored, nevertheless furnish an opportunity of practice for each subject, and were therefore included in arriving at an estimate of the total amount of time spent in practice by the D subjects. For this reason, therefore, there are only 24 trials for the D group to compare with every 30 trials in the M group. This ensures that the amount of time of practice for the two groups would be identical in each of the three periods of practice (300 secs. = 30 x 10 secs. = 24 x 12½ secs.).

One further exception should be noted—the D group started off by having three consecutive 10-second trials. This was done in order to make comparison possible between the N and D groups with respect to their ability on the task. Statistical analysis failed to show any reason why the null hypothesis should be rejected.

After 300 seconds practice, and again after 600 seconds practice, the D group was given a 10 minute rest, exactly as had the N group. The reason for this will become apparent later. For the moment, we are concerned rather with the evidence for the existence of both ${}_{s}I_{R}$ and I_{R} in our data. Whether we measure I_{R} as suggested by Ammons, or whether we measure it as indicated in the diagram, there is no doubt that the curve of performance of the M group after rest fails to rise to the same level as that of the D group. The extent of this failure, according to Hull and Kimble, would be a measure of the amount of ${}_{s}I_{R}$, or permanent work decrement, and has been indicated as such in Figure 2.

To assess the significance of the difference in performance between the M and D Groups after the two rest intervals appeared to be a task of supererogation as there was practically no overlap between the two sets of scores. However, analysis of variance was performed both on the original scores and on the square root transformation of the scores. (This transformation appeared necessary as there is a linear relationship between average score and variation about the average. The square roots as tested with Bartlett's test were found to vary homogeneously). Differences were significant well beyond the. 001 level, thus leaving little doubt about the reality of ${}_{s}I_{R}$.

I_{R} will be seen to produce much smaller effects than ${}_{s}I_{R}$. These effects however, are also fully significant statistically as has been shown in a previous publication. We may conclude therefore that our data support the Hullian theory regarding the existence of both I_{R} and ${}_{s}I_{R}$.

5. Experimental Findings

The theory outlined above makes it possible for us to make certain

predictions which can be experimentally tested. These hypotheses will be stated seriatim, together with a brief discussion showing how they derive from the general theory, and a demonstration of relevant experimental findings.

H.1: A rest of sufficient length to allow the total amount of reactive inhibition accumulated during preceding practice to dissipate will result in a long-term post-rest increment in performance following massed practice, but no following distributed practice.

This hypothesis follows directly from our general theory. Massed practice allows I_R to accumulate to the point where involuntary rest pauses are enforced; these then lead to the growth of ${}_sI_R$. Lack of reinforcement during the first minute or so after rest leads to the extinction of ${}_sI_R$. In distributed practice I_R is not allowed to reach a sufficiently high level for involuntary rest pauses to appear, and therefore no ${}_sI_R$ is generated. Consequently, we should not be able to find anything corresponding to the extinction of this (non-existent) ${}_sI_R$ after distributed practice.

For proof of this hypothesis we may turn to Figure 2 which contrasts the performance of 50 subjects during massed practice with that of 25 subjects during distributed practice. Details of the experiment have already been given in an earlier section of this paper. Simple inspection of this diagram will show that our hypothesis is verified. There is nothing in the curves of distributed practice following the two 10-minute rest intervals R_1 and R_2 which remotely resembles the steady, long-continued rise which is so noticeable under conditions of massed practice. There is, indeed, in both cases a rise from the first to the second 10-second practice period in the distributed practice curve, but this rise is not continued, as it is in the case of the massed practice curves, for a period of 60-90 seconds. It seems likely, therefore, that what we are dealing with in the curve of distributed practice is warm-up effect, producing a rise in performance continued for 20-seconds at most. Such a rise is also apparent in a figure given by Adams (40) in his paper on "Warm-up decrement in performance on the pursuit rotor"; as the rest pauses in his case were of 24 hours duration rather than of 10 minutes duration, the warm-up effect is rather stronger. Nevertheless, in his case also it appears to reach its maximum after 20 seconds or so.

H.2: Post-rest increment due to the extinction of conditioned inhibition through a failure of reinforcement will be more rapid and more extensive after the second rest period (R_2) than after the first (R_1).

This prediction follows immediately from the fact that extinction phenomena are more easily obtained on the second or subsequent occasion than

they are on the first occasion; this is a well-known principle of conditioning (41). If the rapid rise in our massed practice curves after rest is indeed due to extinction, then repetition of this extinction should make it both more rapid and marked.

Casual inspection of Figure 2 indicates that this hypothesis is also verified. 110 seconds are required to reach the top of the curve after R_1, but only 60 seconds after R_2. Thus, the rate of increase has almost doubled from one curve to the other. The amount of increase is 10 % after R_1 and 12 % after R_2. However, casual inspection in this case is clearly not enough to establish the significance of the observed phenomena and a proper test becomes requisite.

Such a test requires the use of analysis of variance and necessitates the splitting up of the differences between the three series into differences in (1) *Level* (average performance in the entire series); (2) *Gradient* (rectilinear regression of score on run); (3) *Curvature* (progressive change in the regression rate over the series); and (4) *Chance Fluctuations* (42). As means and variances were related in a simple rectilinear fashion, the original units of measurement had to be transformed. Square roots were accordingly taken and tested for homogeneity with Bartlett's test. This gave a chi square value of 95.827 for 89 d.f. and a P of .29. (The alternative of a logarithmic transformation was also considered but found unsuitable).

The total variance of the transformed scores breaks down into three main parts: the variance between persons, which, although substantial, is of no particular interest to this enquiry; the variance between runs, which is to be analysed in detail; and the remainder due to inconsistencies in individual performance on different runs, which provides an estimate of mean square variance due to chance. Results are given in Table I. Average performance on all the runs is 2.52 in Series 1, 4.65 in Series 2, and 5.34 in Series 3. The massive mean square variance "between levels" given in Table I shows that the differences between these averages are highly significant. The regression of score on run is +.0565 in Series 1, +.0039 in Series 2 and —.0161 in Series 3. The analysis shows that these gradients differ significantly. Curvature is significant and similar in all three series, but there is no substantial significance attached to the apparently greater steepness in post-rest increment in Series 3 as compared with Series 2. This failure of the transformed scores to reach significance may in part at least be a function of the transformation of scores undertaken to fit the requirements of the statistical analysis. The very close fit of the curves to the original observations as shown in Figure 2 suggests (but does not prove) that on repetition the same effect would be obtained again.

TABLE I

Analysis of the variance of the transformed scores

Source of Variance	Sum of squares	d.f.	m.s.v.
Main components:			
Variance between persons	5,831.75	49	
Variance between runs	7,142.31	89	
Residual error variance	5,783.33	4,361	1.326
Total	18,757.39	4,499	
Detailed analysis of the variance between runs:			
Variance accounted for by			
(a) differences between levels of performance in different series	6,482.92	2	3241.460
(b) mean regression of score on run, all series combined	73.60	1	73.599
(c) differences in rates of regression in different series.....	316.37	2	158.185
(d) general pattern of departure from a uniform regression rate, observed in all three series	239.07	28	8.538
(e) variations in pattern between series	30.35	56	.542
Total	7,142.31	89	

H.3: A rest, following massed practice continued for a sufficiently long period to allow reactive inhibition to reach its critical level, will result in extinction increment in performance; a rest following practice not sufficiently long continued to allow reactive inhibition to reach its critical level will not result in extinction increment in performance.

It will be clear from the general theory we are investigating that no conditioned inhibition will be generated until the hypothetically enforced involuntary rest pauses which act as reinforcement begin to occur. This, according to the theory, will not be until reactive inhibition reaches its critical level. From the available work of Kimble (43, 44) Ammons (45) and others it would appear that in pursuit rotor learning, the beginning of conditioned inhibition would be around the 90 seconds period, although it is impossible at the moment to say with any degree of exactness where precisely this point should be located. (There is evidence to show that the point is not a constant, but depends on degree of motivation, and it is also likely that there will be individual differences in this respect).

In spite of these doubts about the exact moment of reaching the critical level, our theory would lead us to expect that after two minutes of massed practice little or no extinction increment would be observed, while after long periods, such an increment should make its appearance. Figure 4 shows the results of an experiment which is relevant to this point. 120-second periods of massed practice were separated by 5-minute rests; the data were obtained from 20 women between 18 and 30 years of age (average 25 years). Casual inspection will indicate that there is no evidence for the extinction increment in performance after the first rest pause, but that a very strong increment of this kind is observed after R_2, R_3, R_4, etc. As predicted in H_2, this phenomenon becomes more clearcut and more extensive after later rest pauses; thus, the increment is steeper and more marked after R_3 than after R_2. (After R_4, however, this tendency begins to disappear; a theoretical explanation to cover this phenomenon will be given later).

The reader may find an apparent contradiction in this discussion. If I_R does not reach its critical level during the first practice period, and if I_R completely dissipates during the first rest period, then it would seem that in the second practice period the build-up of I_R will start again *de novo* so that at the end of the second practice period there should again be a failure of I_R to reach its critical level. It is conceivable that such a state of equilibrium might occasionally occur, but what is more likely to have happened is this. Towards the end of the first practice period, I_R reaches its critical level and a limited, rather small amount of ${}_sI_R$ is built up. (As evidence it may be noted that the last thirty seconds practice during the first period fall distinctly below the previous level reached. This would make it appear that the asymptote of I_R has been reached after approximately 90 seconds). A further increment of ${}_sI_R$ is generated by the rest pause following the first practice period. Thus, we do not start *de novo* on the second and successive trial sessions. The possibility must also be considered that the slight amount of ${}_sI_R$ generated during the first period will summate with I_R to form $\dot{I}_R$. This $\dot{I}_R$ would reach an asymptote rather earlier than would I_R without the addition of ${}_sI_R$. This summation of ${}_sI_R$ and I_R to form $\dot{I}_R$ would produce a critical level in the accumulation of inhibition earlier and earlier.

Fortunately the part of this argument relating to the summation of I_R and ${}_sI_R$ is not critical for our hypothesis. There has been a considerable amount of criticism by Koch (46), Osgood (47), Gleitman et al (48), of this hypothesis, and indeed, in terms of Hull's own system, it does not seem reasonable to summate a drive (I_R) and a habit (${}_sI_R$). Osgood (49) and

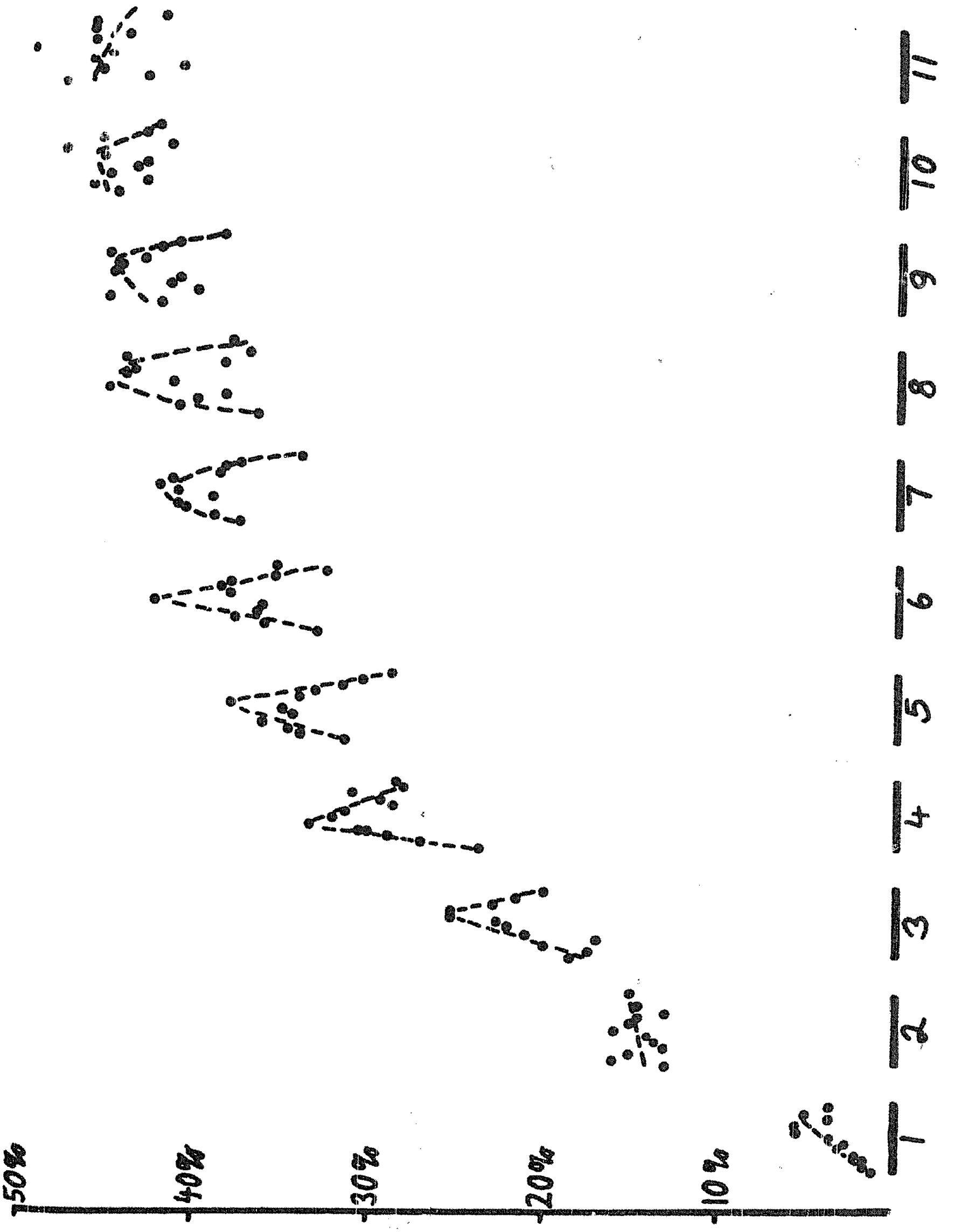

Fig. 4. Reminiscence and extinction increment as a function of rest pauses introduced after two minute massed practice trials on the pursuit rotor.

Zeaman (50), have suggested an alternative formula:

$$_{S}\bar{E}_{R} = (_{S}H_{R} - _{S}I_{R}) \times D - I_{R}$$

but this would still leave us with the difficulty of subtracting a drive (I_R) from a performance potential.

A formula still more in line with Hull's explicit statement of his general theory has been suggested in an unpublished paper by G. Jones. He suggests subtracting negative habit from positive habit, negative drive from positive drive, and using a multiplicative function of habit and drive to form the reaction potential. Symbolically:

$$_{S}\bar{E}_{R} = (_{S}H_{R} - _{S}I_{R})\,(D - I_{R})$$

This formula when multiplied out gives us:

$$_{S}\bar{E}_{R} = (D \times _{S}H_{R}) - (D \times _{S}I_{R}) - (_{S}H_{R} \times I_{R}) + (_{S}I_{R} \times I_{R})$$

From this certain consequences would seem to follow. If we assume that both $_{S}H_{R}$ and $_{S}I_{R}$ grow in accordance with a negatively accelerated growth function reaching a final asymptote, and if we assume that the asymptote for $_{S}H_{R}$ is higher than that for $_{S}I_{R}$ (two assumptions which receive much support from the experimental literature) then we can argue as follows. The growth of $_{S}\bar{E}_{R}$ is determined in its first stage almost exclusively by $D \times _{S}H_{R}$ (I_R has not yet grown to any extent and consequently no $_{S}I_{R}$ has been developed). As I_R develops we get the second stage in which the reaction potential is determined by the expression $(D \times _{S}H_{R}) - (I_R \times _{S}H_{R})$. When I_R reaches a critical point, i.e., when it is equal to D, involuntary rest pauses are enforced which produce $_{S}I_{R}$ and we now reach the third stage in which reaction potential is determined by all four elements in the expanded formula. Finally as $_{S}H_{R}$ and $_{S}I_{R}$ reach their asymptotes, the only element which can change reaction potential will be I_R. From this we may develop our next hypothesis.

> H.4: Near the beginning and towards the end of the growth curve of $_{S}\bar{E}_{R}$ reminiscence effects will be influenced and determined almost exclusively by I_R. During the middle part of the growth of $_{S}\bar{E}_{R}$ reminiscence effects will be influenced to a considerable degree by $_{S}I_{R}$ and its extinction. Consequently correlations between reminiscence scores obtained relatively early and relatively late during the growh of $_{S}\bar{E}_{R}$ should correlate together positively, being dependent on the dissipation of I_R. Similarly reminiscence scores derived from trials occupying the middle part of the growth curve of $_{S}\bar{E}_{R}$ should correlate

positively, being strongly determined by the extinction of ${}_sI_R$. The two sets of reminiscence scores should show a much lower correlation, possibly even zero or a negative one.

The point here made is a very simple one. It may be stated most briefly by saying that the development of conditioned inhibition interferes with the proper determination of reminiscence score in all trials except those at the beginning, i.e., before conditioned inhibition has been developed, and those at the end of practice, i.e., when conditioned inhibition has reached its asymptote.

It may be asked how this can be when our theory effectively splits all inhibition into two parts, namely, I_R and ${}_sI_R$, or temporary work decrement and permanent work decrement. Our measure of temporary work decrement is, in fact, the difference between the last pre-rest trial and the first post-rest trial; how can this measure of the dissipation of I_R be affected by the extinction of ${}_sI_R$ taking place *after* our measurement of reminiscence has been made? The answer to this question, of course, is that the *point* at which measurement takes place is not a geometrical point, i.e., one having no extent, but is, in fact, an average performance over a time interval of 10 seconds. In terms of our theory, and in terms of Figures 2 and 4 as well, this time interval appears to be an exceedingly dynamic one in which a considerable amount of extinction is taking place. Our measurement of reminiscence will only be uninfluenced by ${}_sI_R$ if it could be taken over a very small period of time, such as a fraction of a second. As this is clearly impossible, the consequences delineated in H.4 must follow (51).

Do the predicted results actually occur? In an attempt to answer this question, reminiscence scores were obtained after each of the ten imposed rest intervals shown in Figure 4. These were then correlated and a factor analysis performed (52). In terms of our theory we should find high correlations among reminiscence scores following the first and the last rest pauses; positive correlations among reminiscence scores following intermediate rest pauses; and low or zero correlations between the two sets of reminiscence scores. Table II gives the results of a factor analysis carried out on the intercorrelations. In view of the high standard errors, factor loadings of less than + .30 have been omitted. Two orthogonal factors appear after rotation, carried out according to the dictates of Thurstone's simple structure criterion; these two factors correspond rather well to those demanded by our theory. While the numbers involved in this experiment are small, the results appear in considerable agreement with our hypothesis. (The average correlation among the group R_1, R_2, R_3, R_9, R_{10},

is .36; that between R_4, R_5, R_6, R_7, R_8 is .27. The correlation between the two groups is –.10).

TABLE II

	I	II
R_1	.57	—
R_2	.76	—
R_3	.49	—
R_4	—	.65
R_5	—	37
R_6	—	.68
R_7	—	.40
R_8	—	.47
R_9	.66	—
R_1'	.60	—

6. DISCUSSION

As was mentioned at the beginning of this paper, the experiments here described were carried out in an attempt to decide on the most suitable method for measuring reactive inhibition through the reminiscence effect. The problem which most directly affects this measurement appears to be the so-called "warm-up" effect, which is considered to interfere to a considerable extent with the measurement of reminiscence, and which is being compensated for by many investigators in a somewhat wholesale manner. Our investigation has shown that while the "warm-up" effect does exist, it is of considerably less magnitude than previous theories had led one to assume. Thus, the Ammons correction for warm-up effect is far too drastic and is likely to do more harm than good. If there is to be any correction for warm-up effect, then it appears to be essential that further research should be done, particularly under conditions of distributed practice, where the warm-up effect is not likely to be confounded with the extinction increment effect described in this paper. In particular, the following three questions arise:

(1) Are there individual differences in warm-up, and if so, how are they related to personality factors?
(2) What is the precise rate of growth of warm-up decrement, and how is it related to the stage of practice reached?
(3) To what extent is warm-up itself a learned phenomenon, e.i., to what extent do repeated pauses teach the subject to warm up more quickly and more expertly?

Until answers are obtained to these questions it would not be advisable to correct for warm-up effects. A more advisable procedure might be to

minimize warm-up effects through the procedures suggested by Irion and others.

While thus warm-up effects appear to be less important than had been supposed, another effect which had not hitherto figured in the experimental literature appeared to interfere to a considerable extent with the measurement of reminiscence. This factor, called the "extinction increment" because of its hypothetical cause, namely, the extinction of ${}_{S}I_{R}$ through non-reinforcement, led to an increment in performance which appeared to vitiate the measurement of reminiscence, particularly in the middle stages of practice; in the early and late stages of practice this effect appeared to be of negligible importance. The obvious deduction from this finding would seem to be that there are certain favourable points in the learning curve at which rest pauses may, with advantage, be included if the measurement of reminiscence is the aim of the experiment.

From the broader theoretical point of view, the results of the experiments described here all appear to be deducible from Hullian learning theory, and to the extent that this is so it must undoubtedly be admitted that they strengthen this particular theoretical system. Indeed the writer was surprised to find how closely experimental facts could be integrated with theoretical deductions. Nevertheless, there are certain weaknesses which should be remedied before the hypotheses outlined in this paper can be readily accepted. The main weakness of the general theory appears to be its lack of quantification. We have a rough notion of the type of curve followed by conditioned inhibition and by reactive inhibition, but it is impossible from the literature to derive a formula for these two curves which alone would make possible an exact quantitative prediction of our results. This lack of quantification of intervening variables and hypothetical constructs runs through the whole of psychology, of course, and is not found in Hullian learning theory alone; nevertheless, until the qualitative kind of deduction tested here is replaced by a more quantitative kind of deduction, so long will it be impossible to exclude alternative theories with a very high degree of certainty. Quantitative studies of this type are being carried out at the moment, and it is hoped that a more adequate numerical formulation of the hypotheses here given may be possible later on. Until then, we must remain content with noting the power of learning theory to generate verifiable deductions on a qualitative level.

Summary

The traditional treatment of "warm-up" effects occurring after rest periods is in terms of the loss of muscular and ideational set, a loss which has to be made good during the first few seconds of renewed practice. There are experimental grounds for doubting

whether such "warm-up" effects, although undoubtedly existing, are capable of explaining all the observed post-rest performance increments, and an additional theoretical construct is deduced from learning theory to account for these phenomena. This construct (extinction increment) refers to the hypothetical extinction of conditioned inhibition during practice, after a rest pause during which reactive inhibition (which serves as a reinforcement for conditioned inhibition) has been dissipated. Several deductions are made from this general theory, and results are given from experiments verifying these deductions. The results of this set of experiments make possible an improvement in the measurement of reactive inhibition through the reminiscence effect by clarifying the conditions under which correction for warm-up should be applied.

References

1. The writer is indebted to the Research Fund Committee of the Bethlem Royal and Maudsley Hospitals whose financial assistance made this study possible.
2. Hull, C. L., The place of innate individual and species differences in a natural-science theory of behaviour. *Psychol. Rev.*, 1945, 52, 55–60.
3. Eysenck, H. J., Zur Theorie der Personlichkeitsmessung, (Teil I). *Zeitschrift für Diagnostische Psychologie u. Persönlichkeitsforschung*, 1954, II (No. 2), 87–101; (Teil II) *Ibid.*, 1954, II (No. 3), 171–187.
4. ————, Cortical inhibition, figural after-effect, and the theory of personality. *J. abn. soc. Psychol.*, 1955, 51, 94–106.
5. ————, Reminiscence, drive and personality theory, *ibid.*, to appear.
6. ————, A dynamic theory of anxiety and hysteria. *J. ment. Sci.*, 1955, 101, 28–51.
7. Eysenck, *op. cit.*
8. Hull, C. L., *Principles of Behaviour*. 1943.
9. McGeoch J. A. and Irion, A. L., *The Psychology of Human Learning*. 1952.
10. Eysenck, *op. cit.*
11. Kraepelin, C., Die Arbeitskurve. *Philos. Stud.*, 1902, 19, 459–507.
12. Thorndike, E. L., The curve of work. *Psychol. Rev.*, 1912, 19, 105–194.
13. Bell, H. M., Rest pauses in motor learning as related to Snoddy's hypothesis of mental growth. *Psychol. Monogr.*, 1942, 54, No. 1.
14. Ammons, R. B., Acquisition of motor skill: I. Quantitative analysis and theoretical formulation. *Psychol. Rev.*, 1947, 54, 263–281.
15. Eysenck, *op. cit.*
16. Irion, A. L., Retention and warming-up effects in pairedassociate learning. *J. exper. Psychol.*, 1949, 39, 609–675.
17. ————, Retention as a function of amount of prerecall warming-up. *Amer. Psychologist*, 1949, 4, 219–220.
18. ———— and Wham, D. S., Recovery from retention loss as a function of amount of pre-recall warming-up. *J. exper. Psychol.*, 1951, 41, 242–246.
19. Thune, L. G., Warm-up as a function of level of practice in verbal learning. *Amer. Psychologist*, 1950, 5, 251.
20. Ward, L. B., Reminiscence and rote learning. *Psychol. Mongr.*, 1937, 49, No. 220.
21. McGeoch and Irion *op. cit.*
22. Details of the experiment are given elsewhere. Eysenck H. J., Reminiscence, Drive and Personality Theory, *J. abn. soc. Psychol.*, 1957, in press.

23. Kimble, G. A., An experimental test of a two-factor theory of inhibition. *J. exper. Psychol.*, 1949, 39, 15–23.
24. ———— and Shatel, R. B., The relationship between two kinds of inhibition and the amount of practice. *Ibid.*, 1952, 44, 355–359.
25. Denny, M. B., Frisby, N. and Weaver, J., Rotary pursuit under alternate conditions of distributed and massed practice. *Ibid.*, 1955, 49, 48–54.
26. Ammons, R. B. and Willig, L., Acquisition of motor skill: IV. Effects of repeated periods of massed practice. *J. exper. Psychol.*, 1956, 51, 118–126.
27. Adams, J. A. and Reynolds, B., Effect of shift in distribution of practice conditions following interpolated rest. *Ibid.*, 1954, 47, 32–36.
28. Archer, E. J., Postrest performance in motor learning as a function of prerest degree of distribution of practice. *Ibid.*, 1954, 47, 32–36.
29. Duncan, C. P., The effect of unequal amounts of practice on motor learning before and after rest. *Ibid.*, 1951, 42, 257–264.
30. Reynolds, B. and Adams, J. A., Effect of distribution and shift in distribution of practice within a single training session. *Ibid.*, 1953, 46, 137–145.
31. ———— and Bilodeau, I. McD., Acquisition and retention of three psychomotor tests as a function of distribution of practice during acquisition. *Ibid.*, 1952, 44, 19–26.
32. Schucker, R. E., Stevens, L. B. and Ellis, D. S., A retest for conditioned inhibition in the alphabet-printing task. *Ibid.*, 1953, 46, 97–102.
33. Starkweather, J. A. and Duncan, C. P., A test for conditioned inhibition in motor learning. *Ibid.*, 1954, 47, 351–356.
34. Adams and Reynolds, *op. cit.*
35. Denny, Frisby and Weaver, *op. cit.*
36. Schucker, *op. cit.*
37. The line of best fit, visually fitted to the data in Figure 3 shows little evidence of any departure from regularity due to the effect of the rest pauses. Indeed, in terms of the law of homogeneity as formulated by students of the work decrement (cf. Robinson, Edward S., Work of the Integrated Organism, in *A Handbook of General Experimental Psychology* (Ed. Carl Murchison)) the Alphabet Printing Task would appear unlikely on *a priori* grounds to show much reactive inhibition. The possibility must be considered, of course, that in this task the reminiscence effects are present but counter-balanced by warm-up decrement, and thus not apparent in Figure 3. As a check on this, a correlation was run between the two "reminiscence" scores obtainable from this experiment, i.e., 1st trial of Session II – 10th trial of Session I, and first trial of Session III – 10th trial of Session II. In the pursuit rotor experiment this correlation had been very significant statistically Eysenck, H. J., Reminiscence, drive and personality theory, *J. abn. soc. Psychol.*, to appear); in the present experiment it was not significantly different from zero (r = .003). We must therefore discount this possibility.
38. Ammons, C. H., *An experimental study of temporary and permanent inhibitory effects associated with acquisition of a simple perceptual motor skill.* Unpublished Ph. D. Thesis. Univ. of Kentucky, 1955.
39. ————, Task for the study of perceptual learning and performance variables. *Percept. Motor Skills*, 1955, 5, 11–14.

40. Adams, J. A., Warm-up decrement in performance on the pursuit rotor. *Amer. J. Psychol.*, 1952, 65, 404–414.
41. Hilgard, E. B. and Marquis, D., *Conditioning and learning*. 1940.
42. The writer is indebted to P. Slater for advice relating to the statistical analysis here presented.
43. Kimble, *op. cit.*
44. ——— and Shatel, *op. cit.*
45. Ammons, R. B., Acquisition of motor skill: II Rotary pursuit performance with continued practice before and after a single rest. *J. exper. Psychol.*, 1947, 37, 393–411.
46. Koch, S. and Hull, Clark L., in *Modern Learning Theory*. 1954.
47. Osgood, C. E., *Method and theory in experimental psychology*. 1953.
48. Gleitman, H., Nachmias, J. and Neisser, U., The S.R. reinforcement theory of extinction. *Psychol. Rev.*, 1954, 61, No. 1., 23–33.
49. Osgood, *op. cit.*
50. Zeaman, D., Response latency as a function of the amount of reinforcement. *J. exper. Psychol.*, 1949, 39, 466–483.
51. We may find here an explanation also of the fact that the extinction increment appears to vanish during the last few trials. In terms of conditioning theory, repeated extinctions become very much more rapid until at the end they would be expected to be practically instantaneous. Thus it might be argued that the extinction increment occurs wholly during the first 10 seconds trial of the last session. An alternative hypothesis to account for this effect may be related to asymptote or "ceiling" effects. As the asymptote of performance is reached there is less and less room for extinction increment to occur. Both these hypotheses may, in fact, be correct and supplement each other. One possible deduction to be made from the first hypothesis would be that reminiscence scores include more and more extinction increment and become larger in later sessions. An opposite prediction would be made in terms of our second hypothesis. Unfortunately it is impossible to make an empirical test of this, as we would require a more rational unit, such as Hull's *habs* instead of the raw scores we have been using. Such refinements must await the construction of a more quantitative theory that we have available at present.
52. The writer is indebted to Mr. K. H. Star for carrying out this analysis.