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Periodicities in Motor Performance as a Function of Work-Surface Height

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Although motor learning is generally assumed to be an orderly process, the observed performance curves of individuals and groups of individuals are usually rather irregular with observed points falling both above and below the general trend of the curve. This conflict between theory and observation has typically been resolved by attributing such variations to the chance operation of uncontrolled variables. However, a recent theory describes a mechanism by which such variations might occur. The present paper extends this theory to the problem of performance variability, and presents an analysis of performance curves obtained under two conditions of work-surface height to test this extension.

THEORETICAL BACKGROUND

In his theoretical interpretation of some of the phenomena of motor learning, Kimble (4,5) has postulated an inhibitory process termed reactive inhibition (I_R). Four of the characteristics ascribed to I_R are of importance for the present discussion: (1) it is a negative drive developed by response evocation which depresses performance; (2) when present in a certain critical or threshold amount it will produce resting; (3) it dissipates during rest periods; (4) the amount of I_R generated by a response is a direct function of the effortfulness of the response.

Using this theoretical structure, Kimble sketches the following picture of an organism working continuously with no scheduled rest pauses (4, p. 16):

> Since I_R is a drive, it seems only reasonable to suppose that the accumulation of a certain critical amount will automatically produce resting . . . Presumably, once I_R is reduced to below the critical level, the organism driven by motivation to perform the task at hand will resume work and continue working until the critical level of I_R is reached again. Then it will rest, reducing I_R; start work again, increasing I_R and so on.

Although Kimble does not specify the duration of these resting responses, direct evidence of such rests comes from the momentary hesitations or blocks in performance observed by Bills during continuous mental work (1). These inhibition-dissipating rests could be responsible for some of the variation present in performance curves: they would lower performance during the time interval in which they occur, and would heighten it in susequent time intervals because of the dissipation of inhibition.

Such a theory leads to certain predictions concerning the effects of work effortfulness on performance variability. Increasing the effortfulness of the work would increase the amount of I_R generated by each response, and would therefore influence the momentary rests taken by the organism to dissipate this inhibition. The organism could adjust to the increased inhibition in two ways: (1) lower its rate of output so that the amount of I_R generated per unit time is within its tolerance limits for such inhibition; (2) maintain its rate of output, but take more frequent resting responses. In actuality, probably both methods are used. However, in an instance where the organism did not reduce its rate of work when the effortfulness of the work was increased, one would predict that its performance curve would be more variable due to the greater frequency of resting responses.

This prediction, which is the primary concern of the present paper, may be stated formally as follows: The variability of individual performance curves should be a direct function of the effortfulness of the work if the curves indicate comparable rates of performance.

METHODOLOGY[1]

Subjects—A total of 60 male undergraduate students served as *S*s. They were divided into two groups of 30 *S*s each so that the groups were equivalent in respect to initial ability on the task used.

Control of work effortfulness—Response effortfulness was manipulated by varying work-surface height. One group of *S*s worked at a height of 3 in. below their elbow (moderate height), while, for the other group, the work surface was set 8 in. above the elbow (high height). Previous research had shown that these heights were significantly different in their effects on both performance and muscular tension (2). Optimal performance and minimum tension were associated with the moderate height, while poorest performance and maximum tension occurred at the high height. It was believed that differences in response effortfulness would be associated with these two heights.

Task and conditions of work.—All Ss worked continuously for 16 min. on the block-turning portion of the Minnesota Rate of Manipulation Test. Each *S* was treated individually, and received stan-

[1]The data reported were obtained in connection with a study of reminiscence in a manipulative task (3).

dardized instructions in the work methods to be used. Motivation was provided in the form of knowledge of results presented every minute during the 16 min. work period.

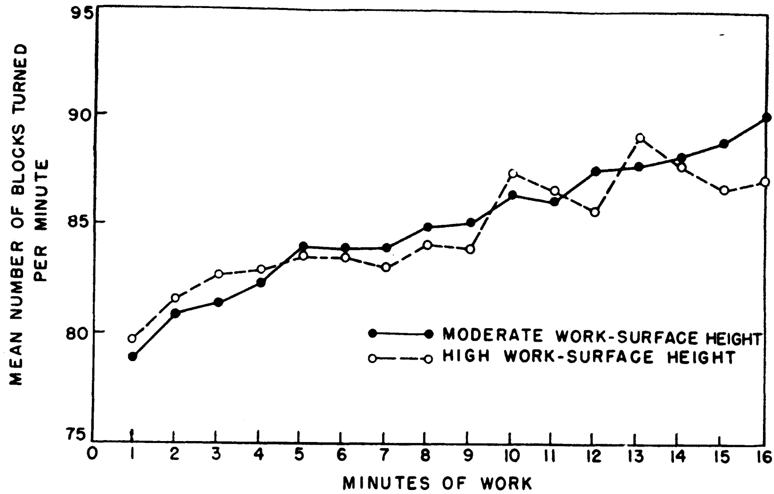

Figure 1.

Results

The mean performance curves at the two work-surface heights are presented in Fig. 1. It can be seen that the curves indicate similar rates of work, and that the curve at the high height is considerably more variable during the later stages of practice.

Table I presents statistical justification of the assumption that the output rates are similar during the later stages of practice. The statistic t rather than analysis of variance is used since the two curves differed in total variance (See Table II).

Table I

Comparison by t of average block-turning performance at the two work-surface heights.

Minutes of work									
8	9	10	11	12	13	14	15	16	8-16 combined
0.39	0.63	0.54	0.31	0.90	0.65	0.21	1.06	1.41	1.19

None of the tabled values of t are significant at the 5% level of confidence. For 58 degrees of freedom, 5% t is 2.00.

Analyses of variance within height conditions are arrayed in Table II. Such analyses are appropriate since Bartlett's test (6, p.

249) indicated that the variance associated with later trials was homogeneous within the two height conditions. It can be seen that, for both the heights, trials and individuals are significant sources of variation. Of more immediate interest, however, is whether the mean curves differ significantly in variability. The tests for departures from linear regression reported in Table II indicate that this is the case. The oscillations of the high height curve produce statistically significant deviations from linear regression, while the moderate height curve is fitted, within the limits of error, by a linear equation.

Table II

Analysis of variance of performance scores from minute 8 to minute 16 of work at the two work-surface heights.

Source	d.f.	Sum of squares	Mean Square	*F*	1%*F*
Moderate work-surface height					
Work (W)	8	748.00	93.50	5.70**	2.60
Linear regression	7	727.08	727.08		
Deviations from linear regression	7	20.92	2.98	0.18	2.73
Subjects (S)	29	9,502.00	327.66	19.97**	1.79
Pooled SxW (Error)	232	3,807.00	16.41		
Total	269	14,057.00			
High work-surface height					
Work (W)	8	698.00	87.25	4.87**	2.60
Linear regression	1	291.21	291.21		
Deviations from linear regression	7	406.79	58.11	3.24**	2.73
Subjects (S)	29	14,185.00	489.14	27.30**	1.79
Pooled SxW (Error)	232	4,158.00	17.92		
Total	269	19,041.00			

**Denotes *F* significant beyond the 1% level of confidence.

Since the prediction made in theoretical portion of the paper dealt with individual variability, it is necessary to determine if the individual performance curves underlying the mean curves also differ in variability. The procedure used involves fitting a linear curve to each *S*'s performance curve and determining the extent to which the actual curve deviates from linear regression. The results of such an analysis are presented in Table III. Although no independent error term is available against which to test deviations from linear regression, it can be seen that the individual curves at the two heights are highly similar in the extent to which they depart from linearity.

Table III

Departures from linearity of individual performance curves from minute 8 to minute 16 of work at the two work-surface heights.

Source	d.f.	Sum of squares	Mean square
Moderate work-surface height			
Within subjects	240	4.555.0	18.98
Linear regression	30	1,156.9	38.56
Deviations from linear regression	210	3,398.1	16.18[a]
Between subjects	29	9,502.0	327.66
Total	269	14,057.0	
High work-surface height			
Within subjects	240	4,856.0	20.23
Linear regression	30	1,929.7	64.33
Deviations from linear regression	210	2,926.3	13.97[a]
Between subjects	29	14,185.0	489.14
Total	269	19,041.0	

[a]Note that deviations from linear regression of the individual curves are less at the high height than at the moderate height, although within-subjects variation is less for the moderate height.

Apparently, the greater periodicity of the mean height performance curve is not due to greater variability of the underlying individual curves. A tentative resolution of this contradiction between the characteristics of the mean performance curves (greater variability at the high height) and the individual curves on which they are based (similar variability at both heights) can be offered. At the moderate height, there might be relatively little correspondence between individual curves in respect to the time at which performance peaks occur, while the variability of the mean high height curve might simply be due to a number of individual curves showing performance peaks at the same point in practice. That such is the case can be seen from Fig. 2, which shows the number of *S*s having a performance peak at each minute of practice for both height conditions. There is a marked tendency, particularly during the later stages of practice, for the performance peaks of *S*s working at the high height to occur during the same trial. In the interests of clarity, this phenomenon will be referred to as phase correspondence.

A chi-square analysis of the data of Fig. 2 is arrayed in Table IV. In the case of the high height, the frequency of occurrence of per-

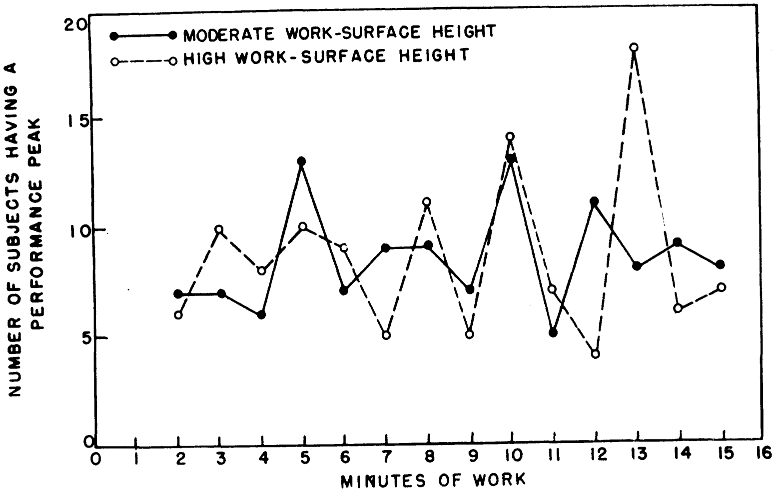

Figure 2.

formance peaks departs significantly from the frequency which would be expected if the peaks were equally distributed throughout the various trials. However, the moderate height data do not depart significantly from this expected frequency. Apparently, the greater variability of the high height performance curve is due to the greater phase correspondence of the underlying individual curves, rather than to greater variability of these curves.

Table IV

Chi-square analysis of a number of subjects having a performance peak at each minute of work for the two work-surface heights. Expected frequencies computed on the hypothesis that peaks are equally distributed throughout minutes 8 to 16 of work.

Minute of work	Moderate work-surface height		High work-surface height	
	Observed frequency of peaks	Expected frequency of peaks	Observed frequency of peaks	Expected frequency of peaks
8	9	8.75	11	9.00
9	7	8.75	5	9.00
10	13	8.75	14	9.00
11	5	8.75	7	9.00
12	11	8.75	4	9.00
13	8	8.75	18	9.00
14	9	8.75	6	9.00
15	8	8.75	7	9.00
16	----	--------	----	--------
Total	70	70	72	72
Chi-square	7.63		18.67**	

**Denotes chi-square significant at the 1% level of confidence. For 7 d.f., 1% and 5% chi-square are, respectively, 18.48 and 14.07.

Table V anticipates one possible explanation of this phase correspondence by determining if there is any difference between the two groups of *S*s during later trials in respect to either (1) the mean time elapsing between performance peaks, or (2) the variability of the mean time between peaks. It can be seen that neither of these measures discriminate between the high height and the moderate height group.

Table V

Comparison of the two work-surface heights in respect to mean time elapsing between performance peaks.

Work-surface height	Mean time (min.)	*t*	Variance of mean time	*F*
Moderate	2.65	0.70[a]	0.748	1.14[a]
High	2.83		0.815	

[a]Neither of these values are significant at the 5% level of confidence.

Discussion

It will be recalled that the purpose of this paper was to test the prediction that the variability of individual performance curves is a direct function of work effortfulness. While it was true that the variability of mean performance curves was greater under greater work effortfulness (high height), the underlying individual curves did not differ in variability. Clearly, the obtained data are inconsistent with the prediction. The fact that the mean curves based on the individual curves did differ in variability is irrevelant to the hypothesis, which was specifically concerned with individual variability.

The task of interpretation lies in specifying (1) what significance attaches to the phase correspondence of the individual curves at the high height, and (2) whether the data provide an adequate test of the prediction made from the assumption that inhibition-dissipating rests are a determiner of performance variability.

The obtained data are not of much help in advancing a reasonable explanation of the greater phase correspondence of the individual curves at the high height. Tables IV and V indicate that the individual curves at the two heights do not differ significantly in respect to the number of performance peaks, the mean time elapsing between peaks, or the variability of the mean time between peaks. These are three characteristics which might influence the probability of obtaining *S*s of similar phase characteristics. The failure to find significant differences in them blocks the only avenue of explanation apparent to the author, and suggests that the phase correspondence observed might be a property of the particular group of *S*s in the high height group. A repetition of the experiment with different *S*s would provide the best basis for deciding whether phase correspondence is a phenomenon consistently associated with high work-surface heights.

Two problems may be noted in determining if the data provide an adequate test of the theory that performance variability is partially caused by inhibition-dissipating rests. First, there is the question of whether response effortfulness is influenced by work-surface height. Although previous results indicate that the work-surface height influences muscular tension, they also indicate that the tension induced at the high height is localized in the upper arms, back, and shoulders. (2). Since these muscle systems are relatively remote from the lower arms and hands which actually perform the block turning, it may be that varying work-surface height does not have a direct enough influence on the effortfulness of the response used to index performance.

Second, the data may be criticized on the basis of the relatively coarse time units in which performance was measured. If the frequency of the postulated rests is greater than once per minute, output per minute scores would not reflect their influence.

These considerations clearly indicate the desirability of more adequate tests of the deductions which can be made from considering the influence of inhibition-dissipating rests on performance. Specifically, two characteristics of a more adequate test of the deduction that performance variability is an increasing function of response effortfulness can be suggested: (1) control of response effort so that is intimately related to the response measured; (2) measuring output over narrow time intervals.

Summary

The performance curves of two groups of 30 *S*s working continuously on a block-turning task under two conditions of work-surface height were examined for differences in variability. Statistical analysis indicated that the mean curve at the high work-surface height was more variable than the mean curve at the moderate height. However, individual performance curves at the two heights did not differ in respect to (1) departures from linearity, (2) number of performance peaks, and (3) differences between *S*s in elapsed time between peaks.

The results are interpreted as due to a chance correspondence in

the phase characteristics of *S*s working at the high height. Inconsistency of the results with predictions made from the assumption that inhibition-dissipating rests are a determiner of performance variability is also noted, and recommended procedures for gathering more adequate data to test these predictions are suggested.

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