A CONCEPTUAL APPROACH TO DEVELOPMENT AND VALIDATION OF HIERARCHICAL ACQUISITION IN PSYCHOMOTOR PERFORMANCE

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A hierarchical model for the sequencing of psychomotor skills acquisition is proposed. The model is based on transfer of performance methodology. A series of the experimental studies investigate the viability of a hierarchical model for two levels of difficulties for tasks identifiable with the Control Precision and Rate Control factors. The results are inconclusive regarding the concept of a hierarchical earning for psychomotor skills. The results indicate that substantial transfer of performance may be realized after an initial adjustment period on the transfer task.

Approximately 27 million of the more than 90 million people in the United States labor force are employed in jobs requiring the predominant use of psychomotor skills (U.S. Department of Commerce, 1973, Pp. 1238–1265). A wide spectrum of skills are represented in this figure including assemblers, typists, machinists, dentists and a variety of other occupations. In addition, there are numerous instances in which psychomotor skills are required of everyone desirous of participating in today’s socio-economic environment. Examples of such endeavors include writing, driving an automobile and participation in a variety of sporting events.

Current knowledge of the attributes of human skill is derived from experimental studies of human performance and the acquisition of skill. Human performance research investigates the effects of variables that limit performance including stressors, control and display variables, human information processing capabilities, etc. (Welford, 1968; Poulton, 1974). Skills research investigates the effects of variables that affect the acquisition of skills (Bilodeau, 1966; Goldstein, 1974). Human performance and skills acquisition methodologies have also been combined in studies of multiple task performance (Gopher & North, 1977) and massed and spaced training procedures (Irion, 1966).

The acquisition of psychomotor skills is dependent upon the training methods utilized, which are generally categorized by two dimensions: (a) training methods which impart specific skills in an effective manner through such techniques as knowledge of results, individualized training, simulated and computer based training methodologies, perceptual training, etc., and (b) training methods which optimize learning through the sequential arrangement of the task performances to be learned. Substantial research has been devoted to the former aspects of psychomotor skills acquisition. Relatively little attention has been given to task sequencing.

Task sequencing may be viewed along two dimensions: (a) by adopting the concept of progressive part training; and (b) by sequencing the various task modules in such a way as to achieve maximum overall performance. In the former technique, the learning of the complete task is structured such that the sequence is representative of the logical steps in which the task is performed (Salvendy & Seymour, 1973) or interactions between task dimensions are emphasized (Naylor & Briggs, 1963). The latter technique,
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Based upon transfer of performance between tasks, measures the benefit realized from training on one or more tasks in terms of increased performance or reduced training time for subsequent tasks. This paper describes a conceptual approach to the problem of efficiently sequencing a series of task modules.

Background

Task sequencing has been studied for both cognitive and psychomotor skills. The sequencing of psychomotor tasks has been studied primarily as a function of the relative difficulty of the two tasks. In this approach the transfer of learning in a difficult to easy task sequence is compared with transfer of learning in the easy to difficult training sequence. Reviews of the literature (Day, 1956; Holding, 1962; Briggs, 1969; Boydstun, 1977) indicate that neither of these training sequences is consistently superior, although a difficult to easy training sequence has resulted in greater transfer of learning in more studies than the easy to difficult sequence.

Day (1956) attempted to resolve this issue by classifying experimental results based on the stimulus and response characteristics of the task difficulty variables utilized in experimental studies. Day assumed that training should progress from a task which is perceptually easy to a task which is perceptually difficult, based on stimulus variations. Conversely, response variations should favor a difficult to easy training sequence. This approach met with limited success for response variations, but experimental results based on stimulus variations remained ambiguous. Day attributed these findings to the unknown relationship between the various task difficulty variables and the skills required for performing the tasks.

Holding (1962) notes the ambiguity associated with Day’s procedure of classifying task difficulty variables into stimulus and response categories and investigates the hypothesis that transfer of learning is dependent not only upon relative difficulty but also on the absolute difficulty of the tasks. His results indicate that a difficult to easy training sequence consistently results in greater transfer of learning for all difficulty levels.

Holding (1962) also investigates the relationship between two task difficulty variables (track amplitude and frequency). His results demonstrate a significant interaction between these two variables which concurs with the conflicting experimental results found in previous studies.

The sequencing of cognitive skills has been based on a hierarchical approach to cognitive skills acquisition (Gagne, 1970, 1974). The cognitive skills hierarchy is based on: (a) identifying eight skill categories which range from simple stimulus response connections to problem solving; and (b) arranging these skills hierarchically, based on the optimal sequence of skills acquisition. The resulting theory is a structured learning hierarchy in which subordinate cognitive skills are prerequisite to the acquisition of superordinate skills. The viability of this approach has been demonstrated using transfer of training techniques (Gagne, Mayor, & Paradise, 1962).

The concept of a learning hierarchy has not been investigated for psychomotor skills acquisition. Successful demonstration of a hierarchical model offers two potential benefits: (a) A hierarchical model could aid in the development of efficient training procedures; and (b) a hierarchical model should aid in interpreting conflicting experimental results in the area of transfer of psychomotor performance.

Conceptual Approach for the Hierarchical Sequencing of Psychomotor Skills

The development of a hierarchical structure of psychomotor performance requires the specification of two structural components, including (a) distinct categories of psychomotor skills which are
operationally defined; and, (b) functional relationships between the various categories of psychomotor skills which determine subordinate and superordinate skill categories. The relationships must be established based on criteria which reflect positive transfer of psychomotor performances between subordinate and superordinate skill categories. Furthermore, the development of a hierarchical structure for psychomotor skills must allow for the effects of task difficulty on transfer of psychomotor performance. Ideally, ambiguities obtained in studies of the effect of task difficulty upon task sequencing would be clarified by an interaction between task difficulty and the category of psychomotor skills which is studied.

Several authors have proposed task taxonomies (Melton, 1964; McCormick, Jeannert, & Mecham, 1972; Fleishman, 1972, 1975) which potentially form the components of a hierarchical structure. Perhaps the most general and operationally defined taxonomy of psychomotor performance has been investigated by Fleishman (1954, 1960). The factor characteristics are based on experimental studies which have success fully refined factor definitions (Fleishman, 1953, 1954, 1957, 1958; Fleishman & Hempel, 1954, 1956).

An 11 factorial experimental design would be required to study all factor sequences. The primary characteristics of a hierarchical structure, however, is the subordinate-superordinate relationship between pairs of factors. Thus, a minimum of 110 sequences between pairs of factors must be studied to establish a hierarchy if all other variables are ignored. Initial attempts at establishing a hierarchy of psychomotor skills should concentrate on establishing hierarchical relationships between individual pairs of factors since this property is necessary, but not sufficient, for establishing a hierarchy of psychomotor skills. This approach also allows the experimenter to control other variables, such as task difficulty, with a minimum expenditure of experimental effort.

An Example of an Experimental Study of Transfer between Two Factors

Out of the 11 factors identified by Fleishman (1975) two controls, Control Precision and Rate Control (defined and discussed in the methods section), are initially selected for study since: (a) Previous experimental studies of transfer of psychomotor performance has emphasized control tasks, thus the results of these studies may be utilized to more effectively determine performance parameters for the current study; and (b) the Control Precision and Rate Control factors are well established as distinct psychomotor categories which lend themselves to effective laboratory experimentation through automated computer based display and scoring procedures (Parker & Fleishman, 1960).

An experimental procedure was designed to test two hypotheses: (a) Based on the classification of previous studies (Day, 1956), transfer of performance within each factor should result from a difficult to easy task sequence since tasks within a factor are perceptually similar; and (b) similarly, greater transfer of performance between factors should be obtained in the Rate Control to Control Precision sequence since a Control Precision task utilizes predictable stimuli whereas a Rate Control task utilizes random stimuli.

The selection of appropriate criteria in control tasks is frequently problematic. A frequently used criteria, in control tasks, is the transfer ratios for performance on the initial trials of the transfer task. Hence, this was one of the two criteria utilized in the present study. The second criteria, based on economics considerations, was the total number of trials required to complete each training sequence.
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TABLE 1
Experimental design for Experiments I and II

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Factor</th>
<th>Number of highest Subjects</th>
<th>Track frequencies (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Control Precision</td>
<td>7 (1/cell)</td>
<td>0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5</td>
</tr>
<tr>
<td></td>
<td>Rate Control</td>
<td>7 (1/cell)</td>
<td>0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5</td>
</tr>
<tr>
<td>IIA†</td>
<td>Control Precision</td>
<td>12 (3/cell)</td>
<td>1.0, 2.0, 3.5, 4.5</td>
</tr>
<tr>
<td></td>
<td>Rate Control</td>
<td>9 (3/cell)</td>
<td>0.5, 1.5, 2.5</td>
</tr>
<tr>
<td>IIB</td>
<td>Rate Control</td>
<td>8 (4/cell)</td>
<td>1.0, 2.0</td>
</tr>
<tr>
<td>IIC</td>
<td>Rate Control</td>
<td>10 (5/cell)</td>
<td>0.75, 2.25</td>
</tr>
</tbody>
</table>

Note: Subjects are randomly assigned to each treatment combination. For example, in Experiment IIA, 21 subjects are randomly assigned to the seven treatment combinations. Thus, 12 subjects performed the Control Precision tasks and nine subjects performed the Rate Control tasks (three subjects per track frequency).

† Experiment II consists of three successive experiments. Experiments IIB and IIC were conducted to obtain additional information for the Rate Control tasks.

METHOD

Subjects
Right-handed male student volunteers between the ages of 18 and 30 participated in the experiments. Each subject participated only once in any of the experiments.

Equipment and Tasks
Since the study is based on the notion of hierarchical sequencing of the 11 psychomotor factors, which were experimentally derived over a series of interrelated experiments (Fleishman, 1975); hence, the definitions utilized by Fleishman in those studies are adopted here. Accordingly, Control Precision is measured by a two dimensional, repetitive pursuit tracking task with a position control mechanism. The apparatus constructed for this factor consists of a knob (8.1 cm diameter) and oscilloscope display. An unpredictable tracking pattern was created from six sine waves with random phases and amplitudes. Frequencies were equally spaced. Eight different one-dimensional tracks were used to insure a random track.

Interaction between the subject and the display was controlled by a NOVA minicomputer with a digital and analog converter and disk system. Tracking characters, which were displayed on the oscilloscope, consisted of a dot (follower) and cross (target). Knowledge of results (RMS error) was displayed to the subject at the end of each 30 s trial on a Hazeltine CRT (5.4×2.1 cm characters).

Design of Experiments
A series of three successive studies (Table 1) was conducted to validate the concept of a hierarchy of psychomotor skills between tasks which are representative of the Control Precision and Rate Control factors. Experiments I and II were con-
ducted to determine easy and difficult task levels for each factor. Experiment I (14 subjects) is a pilot study to obtain initial estimates of a subject's performance (RMS error) over a range of task difficulties (0.5 to 3.5 Hz) for each task. Experiment II (39 subjects) was conducted to refine estimates of a subject's performance as a function of task difficulty. Equally easy and difficult tasks (tasks with equal estimated RMS error scores) were selected for the Control Precision and Rate Control tasks for use in Experiment III.

Experiment III (120 subjects) was designed to test for task sequencing effects between factors and task difficulty levels. The combination of factors and task difficulty levels results in four training tasks. The transfer task was restricted to one of the three non-training tasks. Each subject was trained in one of the 12 two-task sequences.

Procedure

Experiments I and II. After completing one demonstration trial, each subject participated in one 33-min tracking session which consisted of fifty 30-s trials separated by 10-s rest periods. The subject was informed that a reduced RMS error score was indicative of improved performance. Knowledge of results was provided at the end of each trial.

Experiment III. After completing one demonstration trial, each subject participated in two experimental sessions separated by a 10-min rest period. The subject continued training in each experimental session until he obtained three successive RMS error scores below the criteria value (established based on results from Experiments I and II). Training within each experimental session consisted of fifty of 30-s trials separated by 10-s rest periods. Knowledge of results was provided at the end of each trial.

Results

Experiment I

A regression analysis of performance (average RMS error for trials 48 to 50) with track frequency indicates that (a) Control Precision—performance is a linear function of highest track frequency ($p < .001$, $R=0.96$); and (b) Rate Control—performance is a quadratic function ($p < .003$, $R=0.98$) of highest track frequency. Estimated performance at track frequencies of 0.5 and 3.5 Hz are 0.14 and 1.84 cm (Control Precision) and 0.17 and 1.34 cm (Rate Control). The significant quadratic term for the Rate Control tasks indicates that performance fails to decrease above approximately 2.5 Hz. Thus, the frequency values utilized in Experiment II for the Rate Control tasks are restricted to values less than 2.5 Hz.

Experiment II

Tests for homogeneity of variance of RMS error scores indicate significant ($p < .05$) differences in variances for the Control Precision tasks. The residuals of a weighted regression analysis (assuming RMS error variance is proportional to the squared track frequency) meets the homogeneity of variance assumption ($p > .10$). The weighted regression is linearly significant ($p < .01$, $R=0.72$), and predicted RMS error scores range from 0.34 to 2.0 cm at 1.0 and 4.5 Hz, respectively.

Tests for homogeneity of variance of RMS error scores indicate significant ($p < .05$) differences in variance for the Rate Control tracks. A residual plot indicated that the variances do not increase regularly as track frequency increases. Separate analyses of this data in the upper (difficult) and lower (easy) track frequencies meet the homogeneity assumption ($p > .40$). Separate regressions in the upper and lower difficulty regions are linearly significant ($p < .01$) and yield RMS error estimates ranging from 0.32 to 0.58 cm and 1.38 to
Table 2

Difficulty values used in Experiment III for Rate Control and Control Precision factors

<table>
<thead>
<tr>
<th>Task difficult</th>
<th>Frequency (Hz)</th>
<th>Mean</th>
<th>Predicted RMS Error centimeters (95% confidence interval)</th>
<th>Frequency (Hz)</th>
<th>Mean</th>
<th>Predicted RMS Error centimeters (95% confidence interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>1.00</td>
<td>0.34</td>
<td>±0.19</td>
<td>0.67</td>
<td>0.34</td>
<td>±0.09</td>
</tr>
<tr>
<td>Difficult</td>
<td>3.50</td>
<td>1.53</td>
<td>±0.33</td>
<td>2.27</td>
<td>1.53</td>
<td>±0.09</td>
</tr>
</tbody>
</table>

1.82 cm at 0.5 and 1.0 and 2.0 to 2.5 Hz, respectively.

Easy and difficult track frequencies are selected for use in Experiment III such that estimated RMS errors are equivalent at comparable difficulty levels between factors (Table 2). The predicted RMS error scores are significantly different (p<.005) between difficulty levels.

**Experiment III**

The number of trials required to reach the RMS criteria score on the training tasks varied between tasks. The mean number of trials required for this were as follows: 61 (Control Precision-easy); 47 (Control Precision-difficult); 39 (Rate Control-easy), and 57 (Rate Control-difficult). These differences are statistically significant (F=3.06, df=3/116, p<.03) indicating a significant error in the RMS error estimates obtained from Experiments I and II. RMS error scores between difficulty levels, however, are significantly different (p<.001). Interpretation of Experiment III results must allow for this result.

An analysis of variance of the total number of trials required to complete the training sequences reveals no significant differences due to task difficulty or factor sequence. The interaction of task difficulty and factor sequence is significant (F=5.17, df=1/112, p<.02) due to the confounded differences in the easy-task training times.

Analysis of transfer ratios for the initial transfer performance indicate significant within factor sequencing effects (F=4.49, df=1/112, p<.04). Thus, transfer sequences which remain within the same factor require less training time. Between factor training sequences are not significantly different.

**Discussion**

The studies discussed here do not provide experimental support for the notion of the existence of a hierarchical structure of psychomotor performance as conceptualized through the hierarchical arrangements of the 11 factors identified by Fleishman (1975). This, in the current study, may possibly be attributed partially to the low power in the statistical analysis due to the extraordinarily large variances between subjects' performances.

This finding may be due to one or more of the following two causes: (a) Each of the four tasks are substantially different from each other as supported by factor analysis studies and (b) an insufficient training time was used in establishing the training sequences. Thus, it is possible that skills developed during the training session were inadequately learned; thus exhibiting different ability requirements than are needed for a higher level proficiency skilled performance of the task (Fleishman, 1954). Thus, it may be hypothesized that the achievement of a higher skilled performance level on the initial task would result in a different transfer of skills to the second task which may suggest the notion of hierar-
chical structuring of psychomotor skills.

It is also possible that the two skill categories utilized in this study are independent, but hierarchically linked to one of the nine remaining skill categories. For example, Multilimb Coordination may be a superordinate class of skills to both Control Precision and Rate Control skills. The present study does not address this question.

Finally, it is noted that the different trends evident in transfer ratios for performance on the initial transfer trials compared to transfer ratios for the number of trials required to complete the transfer task implies that some of the positive effects of learning transfer may have been overlooked by previous studies which emphasize initial performance on the transfer task (Holding, 1962). These results suggest that positive transfer was realized after an initial "adjustment" period wherein subjects were adapting previously learned skills to an altered set of task requirements.

CONCLUSION

The results of the validation study do not clearly support or reject the concept of a hierarchical structure for the acquisition of psychomotor skills. Further study is therefore necessary to establish the viability of this concept. Present results indicate that insufficient training time on the initial training task may account for the lack of more definitive results.

The results suggest that the training time required to complete the transfer task may be a better measure of learning transfer than the traditional measures of initial performance on the transfer task.

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(Received July 7, 1979)