

AD-A146 245 INDIVIDUAL DIFFERENCES IN AUTOMATIC AND CONTROLLED  
INFORMATION PROCESSING(U) ILLINOIS UNIV CHAMPAIGN HUMAN  
ATTENTION RESEARCH LAB P L ACKERMAN ET AL. AUG 84  
UNCLASSIFIED HARL-DNR-8401 N00014-81-K-0034

1/1

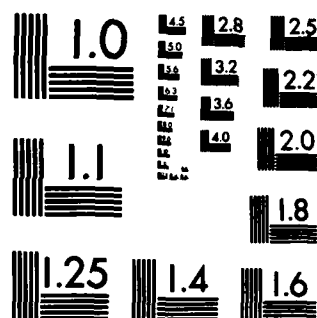
F/G 5/10

NL

END

PAVED

DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

12

# INDIVIDUAL DIFFERENCES IN AUTOMATIC AND CONTROLLED INFORMATION PROCESSING

Phillip L. Ackerman and Walter Schneider

Report HARL - ONR - 8401



DTIC  
ELECTE  
OCT 3 1984  
B

## HUMAN ATTENTION RESEARCH LABORATORY

Psychology Department  
603 E. Daniel  
University of Illinois  
Champaign, Illinois 61820

This document has been approved  
for public release and sale; its  
distribution is unlimited.

*This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences  
Division, Office of Naval Research, under Contract No. N000-14-81-K0034, Contract Authority  
Identification No. NR154-460.*

*Approved for public release; distribution unlimited. Reproduction in whole or in part is permitted for  
any purpose of the United States Government.*

84 09 24 024

AD-A146 245

DTIC FILE COPY

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                      | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                                  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|------------------------------------------------------------------------------|
| 1. REPORT NUMBER<br>HARL-ONR-8401                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 2. GOVT ACCESSION NO.<br>AD A146 245 | 3. RECIPIENT'S CATALOG NUMBER                                                |
| 4. TITLE (and Subtitle)<br>Individual Differences in Automatic and<br>Controlled Information Processing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                      | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report                       |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                      | 6. PERFORMING ORG. REPORT NUMBER<br>HARL-ONR-8401 ✓                          |
| 7. AUTHOR(s)<br>Phillip L. Ackerman & Walter Schneider                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                      | 8. CONTRACT OR GRANT NUMBER(s)<br>N000-14-81-K0034                           |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Department of Psychology<br>University of Illinois<br>Champaign, IL 61820                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                      | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS<br>NR 154-460 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Personnel and Training Research Programs<br>Office of Naval Research<br>Arlington, VA 22217                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                      | 12. REPORT DATE<br>August, 1984                                              |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                      | 13. NUMBER OF PAGES<br>35                                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                      | 15. SECURITY CLASS. (of this report)                                         |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                      | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE                                |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                      |                                                                              |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)<br><br>N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                      |                                                                              |
| 18. SUPPLEMENTARY NOTES<br><br>N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                      |                                                                              |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br><br>Automatic Processing, Controlled Processing, Individual Differences,<br>Practice, Learning, Selection, Training, Abilities, Information Processing                                                                                                                                                                                                                                                                                                                                                                                                              |                                      |                                                                              |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>This report discusses prediction of individual differences in task performance during and subsequent to task practice. Previous literature indicates that pre-practice prediction of post-practice performance declines rapidly as time-on-task increases (for both simple and relatively complex tasks). Based on these effects, traditional conceptions equating general intelligence with learning ability are inconsistent with performance data. The present approach reviews practice effects from an information processing perspective. The distinction- |                                      |                                                                              |

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-LF-014-6601

Unclassified  
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## 20. Abstract. cont.

between two major types of practice effects is outlined and discussed with respect to the automatic and controlled processing framework.

The thrust of the discussion of individual differences and practice is predicated on a theoretical organization which draws together theories of the structure of cognitive/intellectual abilities with aspects of resource theory and elements of automatic and controlled processing. A unified theory of practice is presented. The theory relates ability and performance individual differences to task component consistency characteristics. The supporting data of an experimental study of individual differences in initial, intermediate, and final practiced performance stages are reported.

Proposals regarding new assessment procedures and recommendations for the restructuring of both selection and training methods are described.

DTIC  
SELECTED  
OCT 3 1984

B



|                    |                                     |
|--------------------|-------------------------------------|
| Accession For      |                                     |
| NTIS GRA&I         | <input checked="" type="checkbox"/> |
| DTIC TAB           | <input type="checkbox"/>            |
| Unannounced        | <input type="checkbox"/>            |
| Justification      |                                     |
| By                 |                                     |
| Distribution/      |                                     |
| Availability Codes |                                     |
| Avail and/or       |                                     |
| Dist               | Special                             |
| A-1                |                                     |

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

One major use of psychometric assessment procedures is to predict the performance of individuals after they experience a long training program. For example, college entrance exams are used to predict which applicants will succeed in completing a four-year college educational program. Similarly, military candidates are tested to predict who the best airplane pilots will be after two years of training. Currently used test measures, though, provide only modest predictions of training program success. For example, a composite of college entrance exams correlates  $r = .21$  (Humphreys, 1968) with final semester college grades. Note that these predictors account for less than 20% of the variance in final task performance. This low level of variance-accounted-for poses serious practical problems for test-based selection.

The small proportion of variance-accounted-for also poses theoretical problems for relating intellectual abilities to training success. A basic premise of intelligence theory has been that intelligence is highly related to "learning" (see Sinar, 1946). However, measures of many intellectual abilities are only modest predictors of training program success. It is theoretically discouraging to have measures of intelligence account for only 4 to 20% of the criterion performance variance in a training program.

In order to improve our predictions of training program success we need a better understanding of the relations between individual differences in abilities, underlying task characteristics, task performance, and practice effects. This requires: 1) identification of changes in the characteristics of processing with practice; 2) determination of information processing requirements for tasks; and 3) integration of theory and data concerning normative task performance and practice effects with theory and data concerning individual differences in abilities.

In this chapter we briefly review how performance and information processing change with practice. We discuss the problems that practice effects pose for the assessment and prediction of individual differences in task performance. We describe the automatic/controlled information processing theory and discuss how it allows us to interpret the nature of practice and skilled performance. The automatic/controlled processing framework is elaborated to relate it to ability test measures and theories of individual differences in abilities. We also present the results of an experiment that illustrate the relations between abilities and performance during practice. We end with discussions of future research on the issues relating practice and individual differences.

#### The Problem of Practice

##### Basic Phenomena

The nature of human performance changes so substantially with practice that current ability measures are often poor predictors of practiced performance. As illustrated above, the correlations of most task performance measures and ability measures with practiced performance are typically small (range .22 - .43 for discrimination reaction time, see Fleishman & Hempel, 1955; .15 - .21 for academic grades, see Humphreys, 1968). In addition, as the time on task increases, the

correlation of initial performance and practiced performance decreases (e.g.,  $r = .05$  between trials 1 and 16 on micrometer adjustment task, see Jones, 1970).

Extended practice at performing a task can greatly change the performance level on normative tests. Pellegrino (1983) provided subjects about 8 hours of training on basic spatial abilities tasks (of mental object rotations). Subjects that initially tested at the 39th percentile or below before practice, tested in the 91st percentile or above after training. This improvement in performance remained even when subjects were retested 15 weeks after training. These results show that for a group that showed poor initial performance, a "basic human ability" test score (Primary Mental Abilities - Spatial Relations) can be shifted 1.75 standard deviations in only 8 hours of practice. With such potential instability in a basic ability measure, we should not expect the assessed ability in a novel situation to predict performance following hundreds of hours of practice in a year-long training program.

Practice effects produce qualitative changes in performance of consistent tasks. In a review of the visual search literature, Rabbitt (1982, p. 58) states:

There is no single factor so neglected in experimental psychology as practice effects. In visual search we know that everything changes with practice . . . so far as we know, no single experimental result in the visual search literature is stable with practice.

##### Consistent Practice

Categorical search results (Figure 1, Fisk & Schneider, 1983) illustrate the kind of changes which occur with consistent practice. In the category search task, subjects were presented a memory set ranging from one to four taxonomic categories. Then subjects were presented a display of two probe words. Subjects made a positive response if one of the subsequently presented words was a member of one of the memory set categories. There were two types of search in the experiment. For the VALID MAPPING (VM) conditions, the mapping between the presented category exemplars and the subject's response varied over trials (e.g., on trials where the subject was searching for "animals," the subject would make a positive response to the word "bear;" on other trials when not searching for "animals," the subject would make a negative response to the word "bear"). The varied mapping condition is representative of the processing requirements of novice performance in both varied and consistent search tasks. The second type of search involved a CONSISTENT MAPPING (CM) of categories. In that condition the subject always responded the same way to a given category exemplar (e.g., if the subject was consistently responding to "vehicles," whenever the word "jet" appeared, the subject made a positive response).

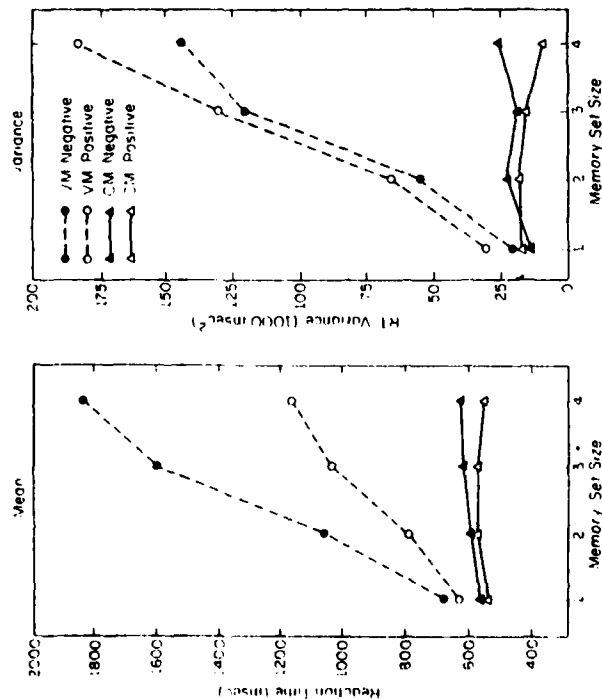


Figure 1. Reaction time means and variances for determining whether either of two words are members of 1 to 4 semantic categories. VM -- varied mapping (unpracticed), CM -- consistent mapping (practiced) search. Pos -- positive, target present responses; Neg -- negative, nontarget trials (data from Fisk & Schneider, 1983).

### Consistent Versus Varied Practice

Distinctions between the varied and consistent mapping conditions may be used to illustrate the gross changes that can occur with practice. For varied or novel search tasks, reaction time (RT) increases linearly with the numbers of items searched for (memory set-size); the positive (or "target present") RT's increased with number of memory items at half the rate of the negative (or "no target present") RT's, and the positive condition within-subject RT variance increased substantially faster than the negative variance. These data indicate that the varied mapping search process is a relatively slow (200 msec per comparison), serial, and self-terminating comparison process. After 13 hours of consistent practice (CM condition), neither the mean search RT levels nor the RT variance show increases with the number of comparisons. The search process appears to be relatively fast (only 2 msec per comparison), and access of the items in memory is parallel. A comparison of the two conditions shows that "consistent" practice can substantially speed the search performance (by a factor of 100) and shift the process from a serial item comparison to a parallel item comparison.

In general, consistent practice at a task speeds performance, enables parallel processing, reduces cognitive effort, enables new strategies, utilizes new abilities to achieve performance, makes the task less consciously demanding, and reduces subjects' control of the task processes (see Fisk & Schneider, 1983).

### Abilities and Practice

Initial performance on complex tasks is generally a poor predictor of final performance. For example, Kennedy, Jones, and Harbeson (1980) found that the correlation between Day 1 and Day 15 performance on a grammatical reasoning task was only  $r = .31$  (accounting for 9% of the variance). The subjects showed different initial performance levels, acquisition rates, and final asymptotes. Initial performance measures on simple tasks are also poor predictors of practiced performance. Results from Adams (1953) show that the correlations of initial performance to final performance drop to  $r = .56$  over about a half hour of practice on a discrimination reaction time task. Similarly, Fleishman and Hempel (1955) report a correlation between initial and practiced performance of  $r = .54$  for one hour of practice on a rotary pursuit task.

There are two major reasons for initial performance to be a poor predictor of final performance. First, during early performance (i.e., the first 15 minutes), many subjects perform activities which are unnecessary as skill develops. For example, they may still be interpreting the instructions, planning new strategies, evaluating performance.

The second reason for poor final task predictions based on initial performance is that practice effects result in radical performance changes early in training. For many skills, processing time is a power function of the number of trials. The pattern of performance is such that the log of the time to complete a response is a linear function of the number of executions of that particular response. Newell and Rosenbloom (1981) show that the power law function holds for a wide range of tasks (e.g., adding digits, editing text, detecting letters, and performing geometry proofs). The power law type of improvement function presents four

problems for predicting final performance from initial performance: 1) Rapid early improvement produces large within-subject variance. 2) Differential experience with related tasks can produce a high initial performance level which is unrepresentative of final performance. 3) Subjects vary in their rate of acquisition, and acquisition rates are very difficult to estimate (see below). 4) Since practice can improve performance over large numbers of trials (e.g., 3 million trials for cigar rolling, Crossman, 1959), the person who is motivated sufficiently to keep practicing may eventually outperform either the fast learner or the fast starter.

The presence of substantial processing and performance changes during practice suggests that measures of individual differences in acquisition rate are critical for predicting final task performance. It should be noted that learning rates are rarely directly assessed during selection assessment procedures. Instead, most abilities tests provide only a brief assessment of current individual differences in performance on fairly novel tasks and tests. For example, typical spatial rotations tests assess spatial ability during the first 2 - 30 minutes of exposure to a novel task (e.g., ETS Kit -- Ekstrom, French, Harman, & Dermen, 1976; DAT -- Bennett, Seashore, & Wesman, 1977). From an information processing viewpoint, the assessed ability levels are determined partly by the amount of previous exposure to related tasks, partly by a subject's ability to comprehend the instructions, and to a lesser (but undetermined) degree, extant learning rate and basic perceptual and motor abilities (e.g., visual acuity). On the other hand, final task performance after an extended training program is probably determined jointly by learning rate, willingness to expend the effort to learn, and abilities. The fact that individual differences on ability measures change with test practice has been well-documented, especially with respect to spatial and perceptual/motor tests (e.g., see Anastasi, 1936; Woodrow, 1946). Thus, many present testing procedures only provide a limited, and certainly confounded measure of the determinants of practiced performance.

A serious problem in the research concerned with assessment of individual differences is in the lack of appropriate data relating intellectual abilities to practice effects. In order to definitively relate these constructs, experimental studies must satisfy two criteria. First, subjects must receive substantial practice for stable performance and learning rates to be determined. For learning a relatively simple, but cognitively involving task, this might require as many as 10 hours of training. Second, in order to obtain reliable correlations between performance and ability measures, substantial subject samples must be used (e.g., 30 subjects from a heterogeneous population). Note that when the range of abilities is restricted (as in college students), the resulting attenuation of association requires a substantially larger sample size to adequately determine ability factors. In Carroll's (1980) review of the cognitive individual differences literature, none of the reviewed studies satisfied the liberal criteria of more than 5 hours of training with more than 30 subjects from a relatively broad population. The current literature indicates that practice greatly changes performance, but we cannot, at present, relate these changes to intellectual abilities.

# Automatic and Controlled Processing

## A Theory of Practice

The striking changes that occur with practice have led many researchers to propose that extended practice brings about qualitative changes in mental processing (e.g., James, 1890; LaBerge, 1975; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). The automatic/controlled processing framework suggests that human performance is the result of two qualitatively different forms of processing (see Schneider, Dumais, & Shiffrin, 1984; Schneider & Fisk, 1983; Shiffrin & Schneider, 1977). Automatic processing is a fast, parallel, fairly effortless process which is not limited by short-term memory capacity, is not under direct subject control, and is used in performing well-developed skilled behaviors. Automatic processing typically develops when subjects deal with the stimulus in a consistent manner over many trials. The rapid, effortless dialing of a well-known phone number is an example of an automatic process. The consistently mapped category search depicted in Figure 1 illustrates the fast, parallel nature of this type of processing. Controlled processing is a slow, effortful, capacity-limited, subject-controlled processing mode that is used to deal with novel, inconsistent, or poorly learned information. Controlled processing is expected when a subject's response to a stimulus varies from trial to trial. The error-prone dialing of a novel phone number is an example of controlled processing. The varied mapping search data depicted in Figure 1 illustrate the slow, serial nature of controlled processing. (For a quantitative representation of automatic/controlled processing, see Schneider 1983).

Automatic and controlled types of processing serve different information processing roles (see Schneider, Dumais, & Shiffrin, 1984). Automatic processing is assumed to perform consistent component processing, to interrupt ongoing controlled processing in order to re-allocate attention, and to bias and prime memory. Controlled processing is assumed to be instrumental in the development of new automatic processes. It is used to deal with novel tasks that cannot be carried out by automatic processing, to maintain the activity of nodes in memory, activate nodes to enable automatic processes, and block or modify automatic processing.

There is rarely any task for which processing is purely automatic or controlled. The two processes generally share the same memory structure and continuously interact. Automatic processing may initiate controlled processing by causing an orienting response. Controlled processing may activate an automatic process. For example, in playing tennis, an expert player may adopt, via controlled processing, a strategy to place the ball in the far right corner. Automatic processes are used in executing this strategy, while controlled processing maintains the strategy.

## Empirical Results

The automatic/controlled processing framework has been used to organize and predict major phenomena of visual search, attention, and skill acquisition (see Schneider & Fisk, 1983; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Consistent practice is predicted to produce substantial improvements in performance

as automatic processing develops (e.g., reducing visual search comparison rates 30%, Fisk & Schneider, 1983). In contrast, varied (or inconsistent) practice exercises only controlled processing and produce little improvement in performance during practice (e.g., no change in letter search performance during 4 months of training, Shiffrin & Schneider, 1977).

Consistent practice greatly reduces the amount of effort necessary to perform a task, allowing controlled processing to be allocated to another task. For example, one experiment has shown that when subjects have already developed automatic processes to perform one task, they can learn to time-share another task with little or no deficit. After about 20 hours of consistent practice in both tasks, subjects were able to perform two search tasks simultaneously nearly as well as they could perform each separately (Fisk & Schneider, 1983; Schneider & Fisk, 1982a, 1982b, 1984). Once automatic processes have developed, subjects have difficulty blocking them from being implemented (e.g., Stroop, 1935; see also Shiffrin & Schneider, 1977; Experiment 4d; and other examples of negative transfer of training, Woodworth, 1938).

The acquisition of skill with practice is assumed to result from the development of automatic processes which are used to perform consistent task components. Automatic processes consist of previously learned or learned-during-practice automatic component productions (see Schneider & Fisk, 1983). The productions are condition-action rules which consistently produce a given action when its conditions are met (Anderson, 1983). The rate of development of new productions is determined by the availability of similar productions (transfer-of-training) and/or the availability of controlled processing for modifying memory (Fisk & Schneider, 1984). When a subject encounters a novel task, each stimulus must be consciously attended to and each decision consciously derived. The ability to maintain information in memory is critical during this initial phase of practice. However, as the production components become well-developed, there is no longer a need for maintaining the critical information in short-term memory. As in a category search task, when a probe word is presented, the activation part of a production is satisfied and an appropriate response is generated without a slow, sequential search. This produces the fast RT functions associated with consistently mapped search performance (Figure 1). For the expert, automatic processes perform consistent transformations of input stimuli and internal memory states into new memory states or responses. The expert requires controlled processing only for dealing with inconsistent aspects or time varying aspects of the task (see Schneider & Fisk, 1983).

#### A Consideration of Abilities

We seek to develop a comprehensive theoretical framework which will relate individual differences in cognitive and intellectual abilities to task performance. Individual differences before, during, and after extended task practice. The automatic/controlled processing framework provides an interpretation of when and how practice alters the nature of, and level of task performance. Of primary importance to this procedure is the mapping of ability theory constructs to characteristics of automatic and controlled processing.

#### Ability Theories and Practice

There are three facets of ability theories which relate to predicting practice effects. These pertain to: 1) aspects of hierarchical theories of intelligence; 2) aspects of the broad ability and personality theory by Cattell and Horn; and 3) the concept of emergent abilities and skills. These three portions of ability theories can be extended to interpret individual differences in task practice effects.

Common to several hierarchical ability theories (e.g., Burt, 1949; Humphreys, 1962, 1979; Vernon, 1961) is the construct of a general intellectual ability factor (or "g"). These theories state that g represents the highest order node in a hierarchy of ability factors. The g factor is implied by the nearly universal positive intercorrelations among cognitive/intellectual measures (Humphreys, 1979). Estimates of the general factor's influence range between 20 and 40% of the total variance of a population of ability tests (Vernon, 1961). In general, the hierarchical theories represent g not as a single ability, or thing in the head (as in Spearman, 1904), but as a construct that represents the communality (or positive manifold) that exists at all levels of intellectual tasks (Humphreys, 1979).

The organization of these hierarchies is based on the generality or specificity of the abilities at each order of nodes. With g, or the most general ability at the highest order, less general ability factors break out at lower nodes. For example, in Vernon's (1961) representation, the second order contains broad major group factors termed "verbal-educational" and "practical-mechanical." At the third order we find more specific abilities (or minor group factors) such as Verbal and Number below the verbal-educational node. As we move down the hierarchy, we would find the component abilities for the group factors (such as Vocabulary, Reading Comprehension, and Associational Fluency under the Verbal factor). Although even lower orders are rarely discussed in the literature, it is important to note that we can conceivably move far enough down such a hierarchy to discover, say, the component processes involved in the storage and retrieval of vocabulary items.

The second facet of ability theory relates to Horn and Cattell's (1966) identification of two major sources of individual differences. One source is identified as representing physiologically-based aspects of mental functioning, or "fluid" abilities. The other source, denoted "crystallized" abilities, is associated with "education or experiential influences" (Horn, 1965). Horn stated that subjects use fluid abilities for tasks requiring rapid "learning and unlearning" of information and on tasks that involve the education of relations or use of logical reasoning. Individual differences on crystallized abilities are assumed to be related to individual differences in the familiarity of tasks, amount of transfer of training advantage (from similar tasks), and in performance on tasks which require retrieval of information from long-term store. While we, and others (e.g., Humphreys, 1982) do not endorse the particular demarcation of "fluid" and "crystallized" abilities postulated by Horn and Cattell, we do concur that abilities have specialized roles in the learning process. More detail is provided below.

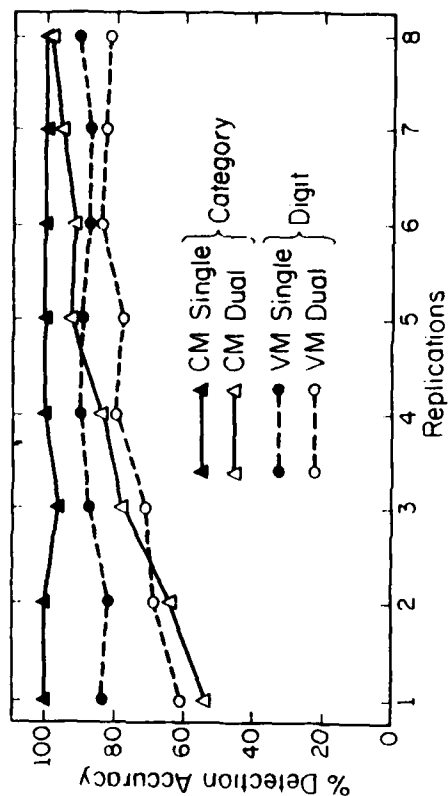


Figure 2. Detection accuracy as a function of hour long sessions. Filled symbols are single task conditions; open symbols are dual task. Dashed lines are the VM digit search; solid lines are CM category search (data from Schneider & Fisk, 1984).

The third facet of ability theories derives from the concept of emergent abilities (Fergusson, 1956; Guilford, 1967; Horn, 1965). The notion is that initial (novel) performance on a task is heavily dependent on general (or broad) abilities which are involved in the subjects' understanding of instructions, selection of processing strategies, short-term memory limitations, reasoning skills, and so on. However, once subjects have the opportunity to practice a task, strategies are established, and subjects internalize the instructions. Thus, as practice continues, the individual differences on the broad and general abilities become less influential determinants of task performance. Finally, after extended practice, specific abilities emerge as the limiting determinants of performance (e.g., see list of perceptual and motor abilities by Fleishman, 1966). For example, initial performance in a video game may be determined by the ability to comprehend the rules and objectives of the game. However, late in practice, perceptual/motor coordination or finger dexterity may "emerge" to limit performance.

#### Performance and Attentional Resources

To relate the ability and information processing areas, we must discuss the attentional requirements of controlled and automatic processing. Norman and Bobrow (1975) have proposed that performance is determined by resource- or data-limitations. Norman and Bobrow define these limits as follows (1975, p. 46):

Whenever an increase in the amount of processing resources can result in improved performance, we say that the task (or performance on that task) is resource-limited.

[When] increasing allocations of processing resources can have no further effect on performance . . . [i.e., performance is independent of the amount of processing resources] . . . we say that the task is data-limited.

In laboratory tasks we have examined resource limitations in consistent and inconsistent tasks. In one experiment subjects performed in a dual-task search procedure. The first task was a consistent category search (e.g., respond whenever an animal word occurs). The second task was a varied mapping digit search (respond if you see the digits "3" or "1"). Four digits and one word were presented every 800 msec. In the dual-task conditions, subjects were encouraged to maximize their digit search performance. Subjects also performed single task versions of category search and digit search in which they ignored the stimuli for the other task. Figure 2 shows the results. This illustrates that the resource load shows little improvement with practice. This illustrates that the resource load for varied search does not change with practice; in other words, the task remains resource-limited. The single task consistent search is at ceiling, and hence, no practice effect can be observed (note, however, see Fisk & Schneider, 1983, for examples of such practice effects). The dual-task conditions show marked practice effects. The category search accuracy improves from 55 to 99%. This improvement illustrates that consistent practice can enable nearly perfect category detection while controlled processing resources are allocated to the digit search task. This suggests that the resources needed for the varied digit search task are no longer necessary for performing the category search. The dual-task digit search also

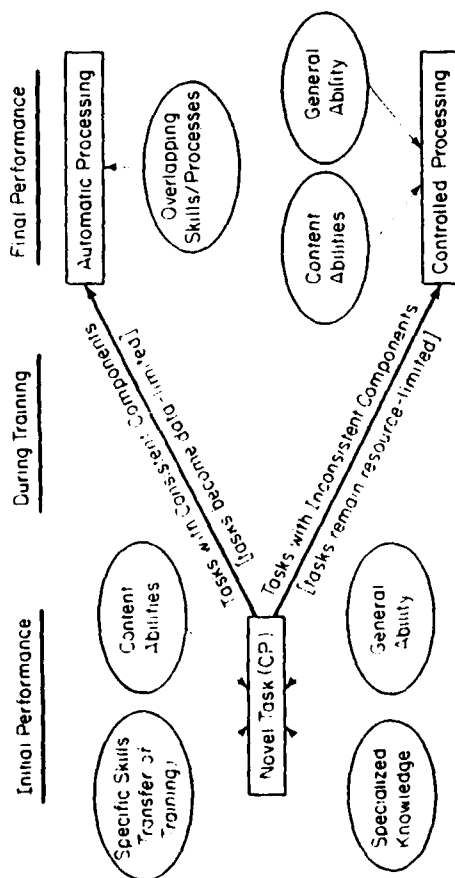


Figure 3. A theory for performance-ability relations. (If specialized knowledge is necessary, the relation between abilities and performance may be non-linear, or even a discontinued function.) Initial correlations between performance and general ability will be higher when instructions are complex, familiarization with equipment, etc. are involved. Since these influences drop out over time, later performance will correlate less with general ability.

shows an improvement with practice. Initially, the dual task digit search accuracy was 63%, and after practice it reached 83%. This practice effect reflects the benefit of allocating resources used initially in category search to the digit search task.

We emphasize that the transition from resource- to data-limited performance practice effects shown in Figure 2 occurs only when consistent task components are involved. When subjects performed dual-task varied digit and varied category search, the resource-limited category search showed no improvement with practice over some 5,000 word searches.

Novel and inconsistent tasks require limited controlled processing resources and hence exhibit resource-limitations. Individual differences in controlled processing resources are interpreted as differences in the amount or efficiency of attentional resources. As automatic processing develops, the availability of controlled processing resources no longer limits performance. When this occurs, performance becomes data-limited. As automatic processing develops, individual differences in controlled processing become less important. Rather, the nature of performance differences must be described at the level of automatic processing component speed, efficiency, or level of development. Below, we will identify these as individual differences in highly specific abilities.

The architecture of attentional resources provides for the mapping of controlled processing resources to ability individual differences. While the field of investigation is still at an early stage, two findings have been relatively well established. That is, evidence has been presented that indicates the presence of general or undifferentiated sources of attentional resources (Kahneman, 1973), as well as broad domains of differentiated attentional resources (e.g., Verbal and Spatial resources posited by Wickens, 1980). We propose that individual differences in controlled processing resource availability or efficiency relate to the individual differences identified in broad and general cognitive/intellectual abilities. Individual differences in automatic processing components, on the other hand, are mapped directly to individual differences in extremely low order, highly specific abilities.

# A Theory of Practice and Performance/Ability Relations

## Basic Statement of the Theory

If we consider an initial domain of tasks that are novel, resource-limited at the beginning of practice, and which allow all subjects to achieve a greater-than-chance (or greater-than-zero) performance level, the theory can be depicted as in Figure 3. Three main principles provide for the major effects in the theory. These are as follows:

### Principle 1.

Broad and general ability individual differences are equated with individual differences in amount or efficiency of attentional resources.

### Principle 2.

The transition from controlled to automatic processing is equated with the transition from resource- to data-limited performance characteristics.

### Principle 3.

The ability determinants of performance are associated with the extent and type of resources required by the task.

From these principles, the figure illustrates what types of abilities will be associated with naive and practiced task performance. For either consistent or inconsistent information processing characteristics, for consistent tasks, general and content-relevant abilities will be associated with the initial performance. Individual differences (because controlled processing resources are required for processing new information). As time-on-task increases, these abilities will be associated with performance. Finally, only specific abilities which tap the skills/processes that overlap with task automatic processing components will correlate with late, well-practiced performance. For predominantly inconsistent tasks, initial, intermediate, and late performance individual differences will be associated with both the general and content-relevant abilities (because controlled processing is required for both novel and familiar inconsistent information).

In addition to the boundary conditions outlined above, changes in task difficulty, content domain, and performance-resource characteristics may be included for predicting other performance-ability relations. (These issues are discussed in Ackerman, 1983).

### Present Theory and Previous Literature

The present theory predicts that transfer-of-training will be determined by the availability of automatic component skills. Automatic productions develop with practice. These productions represent specific abilities or skills to perform consistent processing operations. These specific abilities improve with training and decay with time. The positive transfer-of-training between two tasks will be dependent on whether the consistent components trained in the first task are beneficial to the second task. For example, training to consistently deal with spatial figures can improve performance on related spatial tasks (Pellegrino, 1983). In contrast, the controlled processing resources are comparatively stable. The differential stability of these processes parallels Ferguson's (1956) notion that broad general abilities are stable whereas more specific abilities are not.

The present theory is consistent with a variety of previous data and theoretical statements related to individual differences. *Fleishman* and his colleagues have examined performance-ability relations in consistent hyperperceptual/motor tasks (e.g., Morse code, complex coordination). They found that some broad cognitive abilities (e.g., Verbal, Spatial) correlate moderately with initial task performance. However, correlations between these abilities and performance drop to zero or nonsignificant levels late in practice. On the other hand, motor and related perceptual/motor tests show negligible correlations with early performance but tend to account for moderate proportions of variance as

practice proceeds (see Fleishman & Rich, 1963). In factor analytic studies utilizing a variety of ability tasks, Woodrow (1946) found that initial and final performance after practice identified factors specific to each.

### New Data on Individual Differences in Automatic/Controlled Processing

### Procedural Requirements

Experiments can be designed to obtain fairly pure measures of individual differences in automatic/controlled processing and cognitive abilities. Such experiments must meet special requirements in the: 1) initial conditions; 2) procedure; and 3) analytic techniques.

Two sets of initial conditions for the experiment are related to task and test determination, respectively. Tasks must be chosen such that the experimenter can determine the relative differences in task consistency which allow for the automatic/controlled distinction to be made. As for measures of cognitive abilities, tests should be chosen so that a reliable/stable estimation of broad and/or specific abilities may be established. Factor analytic guidelines suggest using three or four tests per factor to overdetermine ability structures.

Three procedural details are crucial to the success of such an experiment. First, an adequate number of subjects (usually much greater than 30) is necessary for establishing the ability factors as well as for comparing ability individual differences with performance individual differences. *The next requirement is a broad distribution of subject ability levels.* If subjects come from a homogeneous population (such as college students), restriction-of-range of talent will attenuate any subsequent correlations between abilities and performance (McNemar, 1969). In addition, tasks must include substantial amounts of practice. During the first hour of practice, subjects are in the familiarization stage of performance, and individual differences data are unstable. We typically see between-subject stability of performance after the first 3 hours of training on relatively simple cognitive tasks.

Finally, in order to assess the relations between task performance individual differences and ability individual differences, one must choose an analytic procedure that does not lead to spurious results. For example, putting all test and task data together into a factor analysis to find whether task individual differences load on particular ability factors was a commonly used procedure in the 1950's and 1960's (e.g., see Fleishman & Hempel, 1954). One characteristic of learning data is that they are not suitable to common forms of factor analysis (Humphreys, 1960). Instead, one must estimate cognitive ability levels independent of the task data and subsequently make comparisons between abilities and performance (see Fruster & Fleishman, 1967; and below for an example).

## An Empirical Investigation

We have carried out several studies to examine the applicability of automatic and controlled processing concepts for interpretation of practice effects. We will describe an initial study examining consistent and inconsistent processing in

verbal and spatial tasks. The verbal task was a category search task similar to the one described earlier (see Figure 1 above; Fisk & Schneider, 1983). Subjects searched three probe words to determine which of the words was a member of one of a set of three memory set categories. Subjects performed in both consistent and varied mapping search conditions.

This experiment was constructed to test whether the performance-ability relations predicted by the theory were consistent with data collected from a broad sample of subjects over what we consider a moderate amount of task practice (this was 5 hours, or 800 trials per task version). The specific initial predictions were as follows:

1. Normative task performance differences should mirror expectations from automatic and controlled processing theory. That is, the task with predominantly inconsistent, or controlled processing characteristics will show little improvement after initial strategy selection and familiarity with the task. The task which allows for consistent processing requirements will show much greater improvement as automatic processing development ensues. Consistent task performance will level off much later in practice and may not even reach asymptote after many hours of practice (see Fisk & Schneider, 1983; Schneider & Shiffrin, 1977).
2. Abilities may be represented in a hierarchical arrangement by broadness of content, in accordance with many modern ability theories (Humphreys, 1979; Vernon, 1961; etc.). From the chosen tests, two orders of factors are expected. Second order -- g; first order -- Verbal, Spatial, and Perceptual/Motor Speed.

Given these replications of well-established experimental psychometric data, we proceed to predictions of performance-ability relations:

3. General and task-relevant broad content abilities will be highly associated with novel or inconsistent task performance levels.
4. Consistent task characteristics, which allow for automatic processing development, will result in attenuated performance-ability relations with the general and broad content abilities.

5. Shared processing characteristics, whether consistent or inconsistent (such as encoding or responding components and perceptual/motor requirements of the two task versions), will have no differential effects on performance-ability relations. Therefore, both tasks should be equivalently correlated with a broad perceptual/motor speed ability.

An example of the trial frame sequence for the verbal task is presented in Figure 4. On each trial three taxonomic category labels were presented (for 5 sec) on a terminal screen for memorization. Subsequently the screen would clear, and three fixation dots were presented for .5 sec. Immediately afterward, three probe words would be presented (one target and two distractor words). Subjects responded with buttons indicating the position of the target word. Feedback for correct responses included a character spinning off the screen. For incorrect responses, the appropriate word was displayed and an error tone was presented over the subject's headphones. For the consistent task version (CH), separate target and distractor lists were used. For the inconsistent or varied mapping version (VM), target and distractor categories were resampled from a common set on every trial.

The experimental data were based on 63 high school and college students (for details, see Ackerman, 1983). In addition to the task practice, several ability tests were administered over the course of the study. The data-analytic procedure and results are presented below.

In order to provide a valid assessment of performance-ability relation differences between tasks, the experimental data must first be consistent with expectations from the normative and individual difference domains (Predictions [1] and [2] above, respectively). Figure 5 illustrates that normative task performance was consistent with expectations (Prediction 1), the consistent task version (CH) showing a steeper learning curve and a later asymptote than the inconsistent version (VM). Initial performance on both tasks was approximately equal. The VM condition showed little improvement after Session 5. The CH condition data show continued improvement, with mean RT's about 50% faster than the VM condition after eight sessions of practice. In addition, the between-subject's RT standard deviations also reveal data characteristic of consistent and varied conditions. Between-subject variability in the relatively simple, consistent condition attenuates (a 60% decline in standard deviation) with practice as the controlled processing becomes unnecessary (see bottom panel of Figure 5). In contrast, the varied condition controlled processing-related abilities maintain influence throughout practice, and between-subject variability remains stable (a 4% increase in standard deviation over 8 sessions).

The structure was derived by performing a hierarchical factor analysis (see Table 1). Note that the Schmid-Leiman procedure (1957) used these data provides an orthogonal factor structure in two-orders (see discussion by Coll, 1983, for a description of the method). These data are clearly consistent with the theory of cognitive abilities and previous data on these test measures (Ekstrom, French, Herman, & Dermen, 1976). That is, three first order factors of Verbal, Spatial, and Perceptual/Motor Speed were well

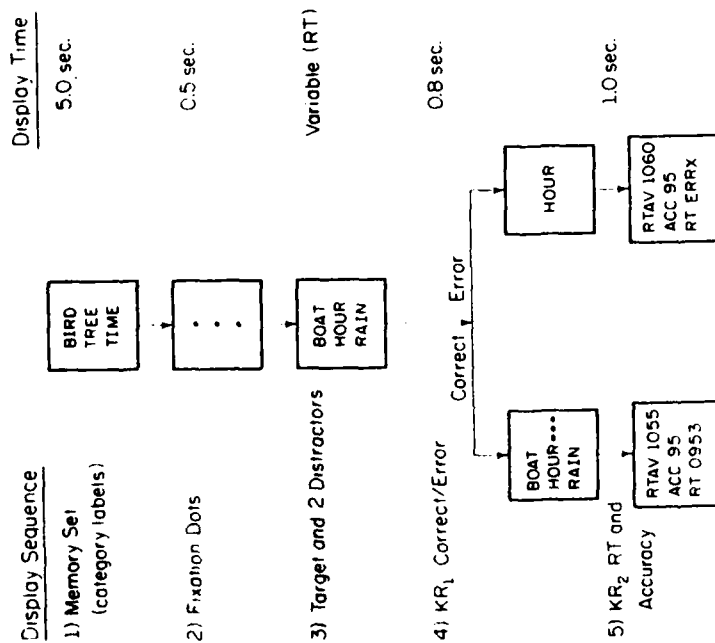


Figure 4. Example of a verbal category search trial display sequence. Memory set size = 3. Probe frame size = 3. KR = knowledge of results feedback. RTAV and ACC are cumulative average reaction time and accuracy, respectively. RT is the reaction time for the present trial (in msec).

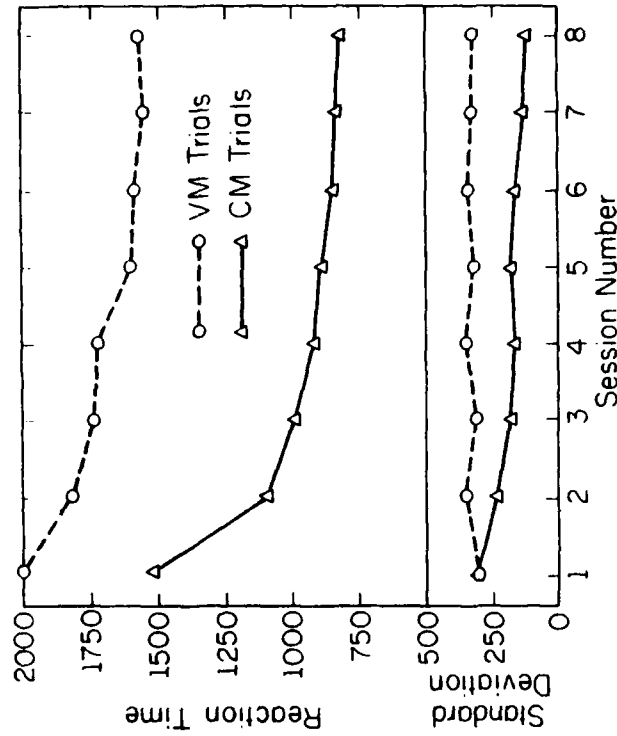


Figure 5. Verbal task RT means and standard deviations for each practice session. (1 session = 5 blocks = 100 trials).

Table 1  
Hierarchical Factor Solution

| Tests                         | Factor |        |         |                            |
|-------------------------------|--------|--------|---------|----------------------------|
|                               | I      | Verbal | Spatial | Perceptual:<br>Motor Speed |
| 1. Finding A's                | .561   | -.065  | .036    | .482                       |
| 2. Vocabulary                 | .590   | .958   | -.081   | -.019                      |
| 3. Analogies                  | .671   | .513   | .042    | .101                       |
| 4. Space Relations            | .570   | .084   | .868    | -.032                      |
| 5. Cube Comparisons           | .470   | -.044  | .883    | -.006                      |
| 6. Card Rotations             | .453   | -.036  | .895    | -.021                      |
| 7. Controlled Associations    | .579   | .802   | .076    | -.067                      |
| 8. Number Comparisons         | .622   | .049   | -.092   | .521                       |
| 9. Letter/Number Substitution | .632   | .051   | .112    | .437                       |
| 10. Raven I S II              | .716   | .229   | .345    | .173                       |

determined by initial factor analysis of the 10 tests (Prediction 2). (We will not be concerned with the Spatial factor here as it pertained to a comparison of spatial task versions.) The positive intercorrelations among these first order factors provided for the determination of the general, second order factor. For this limited sample of subjects and test measures, the second order factor, g, accounted for about 52% of the total variance.

Finally, factor scores (i.e., the subjects' estimated scores on the hypothetical factors) were derived and correlated with the performance measures. The correlations for g, Verbal, and Perceptual/Motor Speed factors and task performance are presented in Figures 6, 7, and 8. Theoretical predictions ([3] and [4] above) were confirmed; the task requiring greater use of controlled processing resources showed larger correlations with g and Verbal abilities. Figures 6 and 7 show that for both the g and Verbal ability factors scores, correlations with the VM (varied mapping) condition are larger during practice than correlations with performance in the CM (consistent mapping) condition. Given the equivalent requirements of the tasks for broad perceptual/motor skills (Prediction 5), the fact that both tasks correlate equivalently with that ability is also consistent with the theory (Figure 8). A spatial task which required subjects to classify rigid rotations and reflections of simple dot figures also provided similar data in support of the theory. Varied task version individual differences were more highly associated with general and task-relevant content abilities than individual differences in consistent task performance. Further details of the spatial task procedures and results are presented in Ackerman (1983).

The fact that these two task versions shared all characteristics but the stimulus mapping consistency makes the divergence in correlations a much more impressive finding than the raw performance-ability correlations indicate. Correlations between performance individual differences on equivalent amounts of practice for the two conditions averaged  $r = .76$ . Therefore, the logical extension is that a more dramatic divergence in correlations could result from sampling tasks which are further separated on the continuum of controlled processing-based and automatic processing-based task characteristics.

It is important to note that although these tasks were relatively simple (from an integration of components viewpoint), 5 hours of practice were not sufficient to establish the attenuation (or trend toward zero) of general and content abilities correlations with the CM condition performance levels (i.e., the Fleishman & Hempel, 1955, and Woodrow, 1946, findings). We speculate that further practice and/or the use of simpler tasks would increase the divergent trend between the consistent and varied conditions.

Two major findings summarize results from this program of research. First, individual differences on tasks which require resource-limited controlled processing are substantially related to individual differences in general and task-relevant content abilities (R approximately .70). Second, when the task dependence on controlled processing resources is reduced (whether by increasing consistency to allow automatic processing components to develop, or by reducing memory load), the relations between task performance and individual differences on the general broad content abilities attenuate.

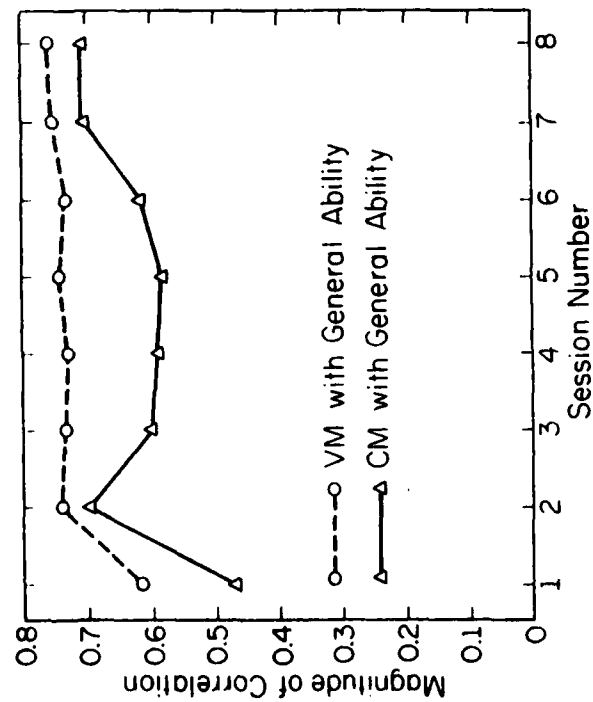


Figure 6. Verbal task: Correlations between derived General Ability factor scores and task session performance (RT).

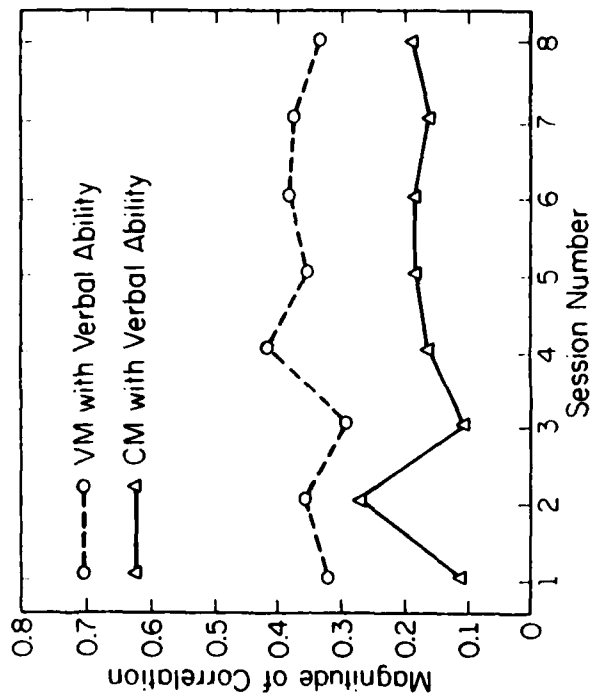


Figure 7. Verbal task: Correlations between derived Verbal Ability factor scores and task session performance (RT).

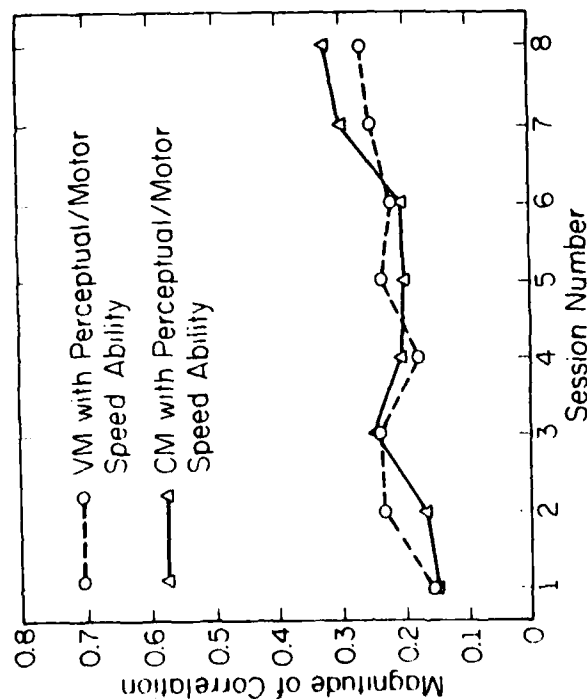


Figure 8. Verbal task: Correlations between derived Perceptual/Motor Speed Ability factor scores and task session performance (RT).

From previous investigations of simple, consistent perceptual/motor task practice, we have already seen the attenuation of broad cognitive abilities correlations with performance over time (e.g., Fleishman & Hespel, 1954, 1955). In addition, such research has indicated that some highly specific abilities/skills do maintain association with performance over practice sessions. In order to estimate such associations for more complex tasks, though, we need to consider a number of additional variables.

#### Extensions from the Theory to Complex Tasks

To extend the present theory to complex tasks, we must specify how practice affects tasks that include many consistent and inconsistent components. For example, in digital electronic troubleshooting, the expected value of a set of logical gates is a consistent processing requirement. Initially, the trainee would have to maintain the logical rules in memory and effortfully interpret the output state from each input state (see Anderson, 1983, for simulations of interpretative application of knowledge). As practice continues, automatic productions develop for the consistent components such that when a given set of input states is presented, the output state is determined with only minor use of short-term memory and controlled processing resources.

Complex tasks also include inconsistent and poorly learned components. In electronic troubleshooting, the trainee applies a varied set of strategies (e.g., bracketing, piggybacking, selective shotgunning; see Bond, 1981). The expert troubleshooter must utilize limited controlled processing resources to activate both strategy and interim state information. Also, if a novel logical element is encountered, controlled processing resources are required to determine the output state. Note that as more of the logical functions are decoded via automatic processing, additional processing resources are available for maintaining strategy and interim state information (see Schneider & Fisk, 1983, for an illustration of this in the acquisition of musical performance skills). If the task requires the development of many components, years of training may be necessary before the task becomes primarily automatic.

#### Improving Predictions

The current state of predicting performance in long-term training programs is modest at best. We have described how practice effects complicate predicting training program success. We believe that standard psychometric procedures typically will be unable to account for more than 20% of the variance when tasks are predominantly consistent. These procedures have been applied now for half a century, and it seems unlikely that new statistical procedures or test questions will greatly increase correlations between test scores and final performance.

Based on our theoretical concepts, normative data, and individual differences data, we suggest new assessment procedures may improve predictions of final performance. These new procedures imply changes in the assessment methodology. First, there must be a task analysis to identify the relevant determinants of performance. For example, the number of automatic productions the trainee must develop and the amount of information that must be actively maintained in memory are

two such determinants. Second, research must more directly examine the relations between cognitive/intellectual abilities and the performance determinants. Third, special testing/training procedures must be developed to determine individual differences in the learning rates for critical skills.

#### Determinants of Performance

Skilled performance in complex tasks is determined by a variety of factors, most of which are not directly measured via standard testing procedures. We briefly mention seven such determinants of performance. We also propose assessment techniques that more directly assess the performance determinants.

For some tasks, there may be physical system factors (e.g., visual acuity, muscle strength, auditory sensitivity) which limit performance. Although visual acuity is a minor factor for a pilot in learning basic control of the aircraft, it may become an important factor in advanced target acquisition. Fleishman and others have contributed a great deal to developing a taxonomy of such factors. (see Fleishman, 1972, 1975, for a review). They have found a number of completely physical abilities which are instrumental in practiced performance (such as Dynamic Strength, Equilibrium, and Stamina). Other factors in this domain may be considered physical or perceptual/motor (such as Finger Dexterity, Aiming, and Arm/Hand Steadiness). When individuals are equivalent on other abilities, practiced performance may be greatly determined by such variables.

The amount of controlled processing resources devoted to any task will be a function of a subject's relative capacity, moderated by motivational variables. Since the use of controlled processing is crucial to understanding task requirements, this factor is especially important to initial task performance individual differences. In addition, controlled processing resource availability determines performance levels in tasks that involve allocation of attention, maintenance of temporary information, strategy switching, and incorporation of new information. Few relatively pure measures in the present domain of intellectual abilities (e.g., digit-span) are commonly used for predicting performance on complex tasks. If controlled processing resources are differentiated (as Wickens, 1980, suggests), it may be necessary to assess task-specific controlled processing resources.

The third factor is motivation. The allocation of controlled processing is effortful. Many of our subjects find it difficult to maintain motivation after the first 5 hours of training. Poor motivation reduces the number of trials practiced and the amount learned per trial, thus reducing the development of automatic processes. Superlative performance skills develop over extended practice (e.g., hundreds of hours of training, see Schneider, in press). The highly motivated trainee with fewer controlled processing skills may surpass a more intelligent but less motivated trainee. Unfortunately, motivation is mostly ignored by classical approaches to ability assessment.

The fourth factor is automatic component availability. This determines what procedural skills the trainee brings to the new situation for transfer or integration. For example, in selecting someone for training in copy editing, it would be critical to assess basic verbal ability. In order to assess automatic

processing components, tests should minimize the consideration of controlled processing to the task. This can be done by: making the task exceed controlled processing capacity (e.g., adding four-digit numbers rather than two-digit numbers), occupying controlled processing by having subjects perform a secondary task, or using speed tests (automatic processing is generally faster than controlled processing).

The fifth factor is declarative knowledge availability. Many skills require a specific knowledge base but do not require that all the knowledge be automatic. For example, a historian needs to know many facts but rarely must retrieve them in situations of high workload or where slowing processing time by a few seconds influences success. This type of general knowledge is frequently assessed in paper and pencil tests (e.g., College Board Entrance Exams).

The sixth factor is learning rate, or how fast new declarative information (see Anderson, 1983) and automatic productions are learned. This factor is determined by: controlled processing resources, motivation, and automatic component availability. In general, standard psychometric tests provide too little practice to directly assess learning rate. Since availability of automatic components depends on specific practice, learning rate assessments may have to be examined in the content domain of the target skill (see below).

The seventh factor relates to strategy use. Some tasks require the skilled practitioner to change strategies to adapt to the situation. For example, an air traffic controller needs to rapidly change strategies of dealing with a single aircraft when weather or traffic patterns change. Most tests assess the ability to perform or acquire a given strategy. Tests may have to be designed to assess the ability to change strategies (e.g., Gopher & Kahneman attention switching task illustrates such a test, 1971).

#### New Assessment Procedures

The automatic/controlled processing perspective emphasizes the need to assess all seven factors to predict practiced performance. Typical ability tests assess only a small subset of these factors. For example, while some tests assess controlled processing almost uniquely, such as the digit-span test; others measure almost uniquely automatic processes, such as vocabulary tests (i.e., retrieval from long-term store). Still other procedures, such as the digit-symbol substitution test, involve both types of processes (since the test is a novel, but consistent mapping of digits and symbols).

We propose that one way selection procedures may be improved is by unconfounding automatic processing and controlled processing demands in ability assessment. Based on our theoretical perspective, final performance derives from stable controlled processing abilities and changing automatic processing abilities. The correlation between these two abilities will change depending on the task and amount of practice. Tests which confound automatic and controlled components will optimally predict performance at a given level of practice. Unconfounded measures should provide separate measures of automatic and controlled components. The weighting of these measures in predicting task performance should change with practice. In this manner, it should be possible to establish selection procedures

more in tune with the training environment demands. In addition, such test measures could conceivably be used to establish criterion-based cutoff scores once the controlled processing/automatic processing task requirements are established through task analysis. These methods may also make it possible to use these testing procedures as diagnostic tools for the tailoring of training programs. We discuss some of the procedures we see as beneficial to this aim.

**Measures of controlled processing resources.** To measure controlled processing resources, we must control or attenuate individual differences attributable to automatic processing. One way of minimizing the role of automatic processing components is to make use of either extremely novel stimuli or extremely familiar stimuli (when most or all subjects have already internalized stimulus codings). However, when novel stimuli are used, the speed at which subjects develop automatic processing encoding components may confound measurement of controlled processing resources.

Another method for deriving estimates of controlled processing resource availability or efficiency is to construct inconsistent tasks that have limited types of strategies that may be employed. For example, in Chase and Ericsson's (1981) study of digit-span performance, one subject was able to impose a consistent strategy of categorization that ultimately raised his performance from 9 items to 80 items. The strategy the subject employed was based on utilization of a network of well-established categories of running times. However, the strategy would only be effective in dealing with numeric information. By changing the type of stimuli from numbers to letters, the authors were able to show that the subject's controlled processing-based short-term memory capacity was no different than other subjects. Test constructors should examine strategy use via methods such as protocol analysis and comparisons between different measures representing similar constructs (e.g., letters and numbers in the Chase and Ericsson study).

Finally, another possible confounding of content-specific controlled processing resource measurement occurs when subjects use strategies that bring other content resources into use for a specific task/test. For example, some evidence exists for proposing that some subjects may more efficiently encode spatial stimuli by using verbal resources to provide names to stimuli (see relationship of spatial figures and verbal naming data, Glaser & Clark, 1964). Investigators may be able to preclude such extra-content controlled processing by loading memory with a secondary task in the appropriate alternative domain. These dual-task procedures may ultimately be used for assessment of specific controlled processing resource "pools," enabling more accurate measurement of particular content-based processing abilities (see Wickens, 1980).

**Measures of automatic processing development rates.** In order to predict individual differences in ultimate success or failure after practice or training on a complex but consistent task, it is important to assess both the controlled processing resources available for the initial performance of the task and the rate at which subjects will build the automatic processing components. Note that controlled processing resource levels serve as the first hurdle for skilled performance levels to be approached. If it is necessary to maintain, say, eight rules in memory for successful task performance, subjects with insufficient resources to perform the task successfully may show little improvement with

practice. If the task demands involve integrating several automatic processing components, the rate at which such components are established will influence performance both during and after training.

Several methods of assessing learning rate have been reported in the literature over the years, but they have been rarely utilized. Probably the simplest and most straightforward estimate of learning rate (or achievement) is by the partial regression estimate of final performance with initial performance differences partialled out (Formula 1 below; see Cohen & Cohen, 1975, p. 380).

$$(1) \text{ Achievement} = \text{Final Performance} - r \frac{\text{Initial, final}}{\text{Initial}} \text{ Initial Performance (Est.)}$$

A second, more sophisticated procedure involves estimating scores for subjects on different components of individual learning curves (e.g., initial, intermediate, and asymptotic portions of the learning curve). This is accomplished by use of three-mode factor analytic techniques (Tucker, 1966). Although this method of assessing the learning curve patterns of subjects involves considerable calculational complexities, the procedure provides much richer data than just one overall achievement value. Other factor analytic approaches to estimation of learning curve parameters have been successfully used in short-term learning experiments, but not for conditions of extended practice (Allison, 1960; Stake, 1958).

Proficiency at complex tasks involves not just the development of automatic processing components but also the integration of components at various levels of development. So, in addition to assessing learning rate for automatic processing components, one should assess the rate at which subjects integrate components of performance. This may be accomplished by measuring achievement levels for new (integrated) components after subjects have been given either initial component training of short (i.e., less than 50 trials) or long duration (i.e., greater than 1,000 trials). One way of assessing the integrative abilities of subjects involves partialling out individual differences on initial component performance from second component performance measures. Another method for examining this type of ability would be to train all subjects to an arbitrary criterion and then measure subsequent component building performance in isolation.

Finally, some rough estimation of learning rates may be possible by obtaining learning history information from subjects. That is, by examining subjects' experiential successes in other automatic processing-based learning situations, such as high school grades, facility at video games, technical skill at musical instrument playing, typing skill, and so on, we can get an estimate of how likely a subject will develop similar efficiency at other automatic processing task components. Note that this measure does confound many of the variables that determine final performance, such as controlled processing resource capacity, motivation, transfer-of-training opportunity, and so on. However, used in combination with measures of these component variables, this type of data may contribute significantly to prediction of later performance after an extended practice period.

By using purer measures of controlled processing resource availability and automatic processing development rates, researchers should be able to obtain not only more valid predictors of practiced complex task performance differences, but also information useful for diagnostic purposes. These abilities, along with the other instrumental factors mentioned above, can be used to estimate the proportion of subjects that will be able to learn the task in a given training environment. Further, the diagnostic information may be used for restructuring the program in accordance with deficiencies in critical elements of the task. This type of procedure has been used by Frederickson et al. (1983) to remediate learning skills for complex task training and Schneider, Vidulich, and Yeh (1982) for restructuring an air-intercept training environment.

Cautions regarding new assessment procedures. At this stage, there is little evidence about the applied value of our suggested approach. For instance, there is no direct information that refined measures of controlled and automatic processing can improve predictions of practiced performance. We do not know whether such measures are stable or can be estimated during practical testing periods. Automatic process learning rate may vary within an individual depending on the context domain (e.g., it is possible that declarative knowledge learning rates poorly predict spatial learning). Estimates of motivation in an artificial testing situation may poorly predict the motivation of some trainees in the real situation. These all represent unanswered research questions.

#### Closing Comments

The foundation of data and theory of automatic and controlled processing and individual differences in performance-ability relations presented in the preceding pages yields a cautious optimism regarding the future success of selection research and applications. Several final points should be made in concluding our remarks on individual differences and practice.

First, we have little encouragement for investigations aimed at predicting individual differences after practice on simple, initially data-limited, consistent tasks (such as knob adjustment, discrimination of tasks, two-hand coordination, etc. -- see Jones, 1970; Fleishman & Haegele, 1954, 1955). Our theoretical perspective and the data both indicate that individual differences are greatly attenuated in such situations. Variables such as memory limitations, strategy selection, integration of automatic processing components, and transfer of training only have importance on the first several trials of these simple tasks and little influence subsequent to that. Therefore, the only predictions of performance individual differences for these tasks must come from highly specific physical and perceptual/motor control abilities. Even so, the limited amount of stable individual differences variance (relative to random or transient variability) in those tests sets an upper limit of association between performance measures and those abilities (probably around  $r = .2 - .4$  in relatively broad samples of subjects).

Second, when the cognitive processing requirements of a task are increased, even to the limited extent shown in our examples of category search tasks, presently available ability test measures can predict substantial variance in practiced tasks (e.g., the .7 - .8 correlations that we have found). Tasks which

require additional allocation of controlled processing resources or integration of new automatic processing components are expected to correlate even higher with these standard paper and pencil measures.

Third, extended task practice (in excess of 30 hours) with predominantly consistent requirements attenuates performance-ability relations when standard test measures are employed. This set of circumstances is representative of many training requirements, such as air traffic control, electronic troubleshooting, technical adequacy on musical instruments, and so on.

Fourth, for extended practice in consistent task situations, a new generation of ability assessment procedures may substantially improve predictions. The procedures should focus on learning rates and automatic processing integration rates. We propose that assessment procedures must be expanded beyond the 2 - 30 minute limitations of current psychometric conventions. We suggest standard psychometric testing be used in initial selection as the first hurdle. Then, a secondary selection procedure could be used to assess learning rate, motivation, and strategy use within the skill domain. It is important to note that a 20-hour subsequent selection test that can reduce the number of washouts by 1% in a one-year training program would be cost-effective in many domains. We feel properly-designed secondary selection procedures could substantially increase predictive validity.

Finally, data on respective controlled processing-based and automatic processing-related individual differences may be used diagnostically in the development of training or teaching procedures. By analyzing the information processing demands of the criterion task and the initial performance requirements, investigators may undertake appropriate restructuring of the program to accommodate the student/trainee characteristics. For example, if the applicant pool has members with insufficient abilities for part-task integration of components with short training times, remediation (by expanding training) or tailored training may be instituted. In this way, the selection process reduces influence as more applicants can reach appropriate criterion performance levels. Procedures of this type are currently underway, based on this automatic and controlled processing framework and are detailed elsewhere (see Frederickson, et al., 1983; Schneider, Vidulich, & Yeh, 1982).

Even though individual differences in learning and practice have been investigated from many perspectives over the past 70 years, we feel that a fundamental change in approach may produce substantial progress. At this stage of investigation many questions of the heuristic and applied value of the present approach are unanswered. New theoretical developments provide an interpretation of the qualitative changes with practice. New assessment procedures may be able to track these changes and better predict final performance.

## References

- Acherman, P. L. (1983). A theoretical and empirical investigation of individual differences in learning: A synthesis of cognitive ability and information processing perspectives. Unpublished doctoral dissertation, University of Illinois, Urbana-Champaign.
- Adams, J. A. (1953). The prediction of performance at advanced stages of training on a complex psychomotor task (Research Bulletin 53-49). Lackland AFB, TX: Air Research and Development Command: Human Resources Research Center.
- Allison, R. B. (1960). Learning parameters and human abilities (Office of Naval Research Technical Report). Princeton, NJ: Educational Testing Service.
- Anastasi, A. (1936). The influence of specific experience upon mental organization. *Genetic Psychology Monographs*, 18(4), 245-355.
- Anderson, J. R. (1983). The architecture of cognition. Cambridge, MA: Harvard University Press.
- Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1977). Differential Aptitude Tests. New York: Psychological Corp.
- Bond, N. A. (1981). Troubleshooting in the commercial computer industry: A success story. In J. Ramussen & W. B. Rouse (Eds.), Human detection and diagnosis of system failures (pp. 75-85). New York: Plenum Press.
- Burt, C. (1949). The structure of the mind, a review of the results of factor analysis. *British Journal of Educational Psychology*, 19, 110-111, 176-199.
- Carroll, J. B. (1980). Individual difference relations in psychometric and experimental cognitive tasks (Tech. Rep. No. 163). Chapel Hill: University of North Carolina, The L. L. Thurstone Psychometric Laboratory.
- Carroll, J. B. (1983). Studying individual differences in cognitive abilities: Through and beyond factor analysis. In R. F. Dillon & R. R. Schneck (Eds.), Individual differences in cognition, Vol. 1 (pp. 1-34). New York: Academic Press.
- Chase, W. G., & Ericsson, K. A. (1981). Skilled memory. In J. R. Anderson (Ed.), Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum.
- Cohen, J., & Cohen, P. (1975). Applied multivariate regression/correlation analysis for the behavioral sciences. Hillsdale, NJ: Erlbaum.
- Crossman, E. R. F. W. (1959). A theory of the acquisition of speed-skill. *Ergonomics*, 2, 153-166.
- Eklstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). Kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service.
- Ferguson, G. A. (1956). On transfer and the abilities of man. *Canadian Journal of Psychology*, 10, 121-131.
- Fisk, A. D., & Schneider, W. (1983). Category and word search: Generalizing search principles to complex processing. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 9, 177-195.
- Fisk, A. D., & Schneider, W. (1984). Memory as a function of attention, level of processing, and automatization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10, 181-197.
- Fleishman, E. A. (1966). Human abilities and the acquisition of skill. In E. A. Bilodeau (Ed.), The acquisition of skill. New York: Academic Press.
- Fleishman, E. A. (1972). On the relation between abilities, learning, and human performance. *American Psychologist*, 27, 1017-1032.
- Fleishman, E. A. (1975). Toward a taxonomy of human performance. *American Psychologist*, 30, 1127-1149.
- Fleishman, E. A., & Hempel, W. E., Jr. (1954). Changes in factor structure of a complex psychomotor test as a function of practice. *Psychometrika*, 19, 239-252.
- Fleishman, E. A., & Hempel, W. E., Jr. (1955). The relation between abilities and improvement with practice in a visual discrimination reaction task. *Journal of Experimental Psychology*, 49, 301-316.
- Fleishman, E. A., & Rich, S. (1963). Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. *Journal of Experimental Psychology*, 66, 6-11.
- Frederiksen, J. R., Weaver, P. A., Warren, B. M., Gillotte, H. P., Roseberry, A. S., Freeman, B., & Goodman, L. (1983). A componential approach to training reading skills (Report No. 5295, Final Report). Cambridge, MA: Bolt, Beranek and Newman, Inc.
- Frutser, B., & Fleishman, E. A. (1967). A simipical design for the analyses of correlational learning data. *Multivariate Behavioral Research*, 2, 83-88.
- Glanzer, M., & Clark, H. W. (1964). The verbal-loop hypothesis: Conventional figures. *American Journal of Psychology*, 17, 621-626.
- Gopher, D., & Kahneman, D. (1971). Individual differences in attention and the prediction of flight criteria. *Perceptual and Motor Skills*, 33, 1335-1342.
- Guilford, J. P. (1967). The nature of human intelligence. New York: McGraw-Hill.
- Horn, J. L. (1965). Fluid and crystallized intelligence: A factor analytic study of the structure among primary mental abilities. Unpublished doctoral dissertation, University of Illinois, Urbana.

- Horn, J. L., & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized general intelligences. *Journal of Educational Psychology*, 57, 253-270.
- Humphreys, L. G. (1960). Investigation of the simplex. *Psychometrika*, 25, 313-323.
- Humphreys, L. G. (1962). The organization of human abilities. *American Psychologist*, 17, 475-483.
- Humphreys, L. G. (1968). The fleeting nature of the prediction of college academic success. *Journal of Educational Psychology*, 59, 375-380.
- Humphreys, L. G. (1979). The construct of general intelligence. *Intelligence*, 3, 105-120.
- Humphreys, L. G. (1982). The hierarchical factor model and general intelligence. In W. Hirschberg & L. G. Humphreys (Eds.), *Multivariate applications in the social sciences*. Hillsdale, NJ: Erlbaum.
- James, W. (1890). *Principles of psychology*. New York: Holt.
- Jones, M. B. (1970). Rate and terminal processes in skill acquisition. *American Journal of Psychology*, 83, 222-236.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.
- Kennedy, R. S., Jones, M. B., & Harbison, M. M. (1980). Assessing productivity and well-being in Navy workplaces. *Proceedings of the 13th Annual Meeting of the Human Factors Association of Canada*, 8-13.
- Berge, D. (1975). Acquisition of automatic processing in perceptual and associative learning. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V*. New York: Academic Press.
- McNemar, Q. (1969). *Psychological statistics* (4th ed.). New York: Wiley.
- Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition*. Hillsdale, NJ: Erlbaum.
- Norman, D. A., & Bobrow, D. B. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, 7, 44-64.
- Pellegrino, J. M. (1983, April). Individual differences in spatial ability: The effects of practice on components of processing and reference test scores. Paper presented at AERA Meetings, Montreal, Canada.
- Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55-85). Hillsdale, NJ: Erlbaum.

- Rabbitt, P. (1982). Visual search. In C. R. Puff (Ed.), *Handbook of research methods in human memory and cognition* (pp. 27-62). New York: Academic Press.
- Schmid, J., & Leiman, J. M. (1957). The development of hierarchical factor solutions. *Psychometrika*, 22, 53-61.
- Schneider, W. (1983, November). A simulation of automatic/controlled processing predicting attentional and practice effects. Paper presented at the meeting of the Psychonomic Society, San Diego, CA.
- Schneider, W. (in press). Training high performance skills: Fallacies and guidelines. *Human Factors*.
- Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In R. Parasuraman, R. Davis, & J. Beatty (Eds.), *Varieties of attention*. New York: Academic Press.
- Schneider, W., & Fisk, A. D. (1982a). Concurrent automatic and controlled visual search: Can processing occur without resource cost? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 8, 261-278.
- Schneider, W., & Fisk, A. D. (1982b). Degree of consistent training: Improvements in search performance and automatic process development. *Perception & Psychophysics*, 31, 160-168.
- Schneider, W., & Fisk, A. D. (1983). Attention theory and mechanisms for skilled performance. In R. A. Magill (Ed.), *Memory and control of action* (pp. 119-143). New York: North-Holland.
- Schneider, W., & Fisk, A. D. (1984). Automatic category search and its transfer. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10, 1-15.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, 84, 127-190.
- Schneider, W., Vidulich, M., & Yeh, Y. (1982). Training spatial skills for air-traffic control. *Proceedings of the 26th Annual Meeting of the Human Factors Society*, 10-14.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, 84, 127-190.
- Sivall, D. V. (1946). The effects of practice on the factorial equations for perceptual and visual-spatial tasks. Unpublished doctoral dissertation. University of Illinois, Urbana.
- Spearman, C. (1904). General intelligence objectively determined and measured. *American Journal of Psychology*, 15, 201-233.

- Stake, R. E. (1958). Learning parameters, aptitudes and achievements (Office of Naval Research Technical Report). Princeton, NJ: Educational Testing Service.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, 643-662.
- Tucker, L. R. (1966). Learning theory and multivariate experiments: Illustration by determination of generalized learning curves. In R. B. Cattell (Ed.), Handbook of multivariate experimental psychology. Chicago: Rand McNally.
- Vernon, P. E. (1961). The structure of human abilities. New York: Wiley.
- Wickens, C. D. (1980). The structure of attentional resources. In R. S. Nickerson (Ed.), Attention and performance VIII (pp. 239-257). Hillsdale, NJ: Erlbaum.
- Woodrow, H. (1946). The ability to learn. Psychological Review, 53, 147-158.
- Woodworth, R. S. (1938). Experimental psychology. New York: Holt & Co.

HARL Technical Reports

- 8301 Schneider, W. Training High Performance Skills: Fallacies and Guidelines.
- 8401 Ackerman, P. L., & Schneider, W. Individual Differences in Automatic and Controlled Information Processing.
- 8201 Schneider, W., & Fisk, A. D. Attention Theory and Mechanisms for Skilled Performances.
- 8202 Schneider, W., & Fisk, A. D. Automatic Category Search and Its Transfer: Automatic Process Semantic Filtering.
- 8203 Schneider, W., & Fisk, A. D. Processing With and Without Long-term Memory Modification: Attention, Level of Processing, and Word Frequency.
- 8101 Schneider, W. Automatic/Control Processing Concepts and Their Implications for the Training of Skills.
- 8102 Ackerman, P. L., Schneider, W., & Wickens, C. D. Individual Differences and Time-sharing Ability: A Critical Review and Analysis.
- 8103 Fisk, A. D., & Schneider, W. Category and Word Search: Generalizing Search Principles to Complex Processing.
- 8104 Schneider, W., Dumais, S. T., & Shiffrin, R. M. Automatic/Control Processing and Attention.
- 8105 Fisk, A. D., Derrich, W. L., & Schneider, W. The Use of Dual Task Paradigms in Memory Research: A Methodological Assessment and an Evaluation of Effort as a Measure of Levels of Processing.
- 8106 Fisk, A. D., & Schneider, W. Task Versus Component Consistency in the Development of Automatic Processes: Consistent Attending Versus Consistent Responding.

CNS Distribution List

Dr. Robert Breuss, Navy Training Equipment Center, Orlando, FL  
 Dr. Susan Chipman, Office of Naval Research, Arlington, VA  
 Dr. Charles E. Davis, Office of Naval Research, Arlington, VA  
 Dr. Marshall J. Farr, Office of Naval Research, Arlington, VA  
 Dr. Pat Federico, NROTC, San Diego, CA  
 Dr. Paul Foley, Navy Personnel R&D Center, San Diego, CA  
 Dr. Dick Hoshan, NAVOP-135, Washington, DC  
 Dr. James McBride, Navy Personnel R&D, San Diego, CA  
 Dr. Alfred F. Sade, Naval Training Equipment Center, Orlando, FL  
 Dr. Richard Sorenson, Navy Personnel R&D Center, San Diego, CA  
 Dr. Brad Symphon, Navy Personnel R&D Center, San Diego, CA  
 Dr. Ronald Weitzman, Naval Postgraduate School, Monterey, CA  
 Dr. Douglas Wetzel, Navy Personnel R&D Center  
 Dr. Jerry Lehman, CAT Project Office, HQ Marine Corps, Washington, DC  
 Dr. Clessen Martin, Army Research Institute, Alexandria, VA  
 Dr. Ray Perez, PERI-11, Alexandria, VA  
 Dr. Genevieve Haddad, Life Sciences Directorate, AFOSR, Bolling AFB, DC  
 Dr. Patrick Kyllonen, AFRL/PM, Brooks AFB, TX  
 Dr. Clarence McCormick, HQ, MEDCOM, MEDCT-P, North Chicago, IL  
 Dr. Randolph Park, AFRL/PM, Brooks AFB, TX  
 Dr. Thomas A. Warr, US Coast Guard Institute, Oklahoma City, OK  
 Dr. Joseph L. Young, National Science Foundation, Washington, DC  
 Dr. Isaac Bejar, Educational Testing Service, Princeton, NJ  
 Dr. Menucha Birenbaum, Tel Aviv University, Tel Aviv, Israel  
 Dr. R. Darrell Bock, University of Chicago, Chicago, IL  
 Dr. Robert Brennan, American College Testing Programs, Iowa City, IA  
 Dr. Pat Carpenter, Carnegie Mellon University, Pittsburgh, PA  
 Dr. Lynn A. Cooper, University of Pittsburgh, Pittsburgh, PA  
 Dr. Timothy Davey, University of Illinois, Urbana, IL  
 Dr. Dattpredat Davi, Syracuse University, Syracuse, NY  
 Dr. Fritz Drasgow, University of Illinois, Champaign, IL  
 Dr. Stephen Dunbar, University of Iowa, Iowa City, IA  
 Dr. John M. Eddins, University of Illinois, Urbana, IL  
 Dr. Jeffrey Elean, University of California-San Diego, La Jolla, CA  
 Dr. Anders Ericsson, University of Colorado, Boulder, CO  
 Dr. Benjamin A. Fairbank, Jr., Performance Metrics, San Antonio, TX  
 Dr. Don Gentner, University of California-San Diego, La Jolla, CA  
 Dr. Daniel Gopher, TECHNION, Haifa, Israel  
 Dr. Bert Green, Johns Hopkins University, Baltimore, MD  
 Dr. Michael Habon, University of Dusseldorf, Dusseldorf, W Germany  
 Dr. Delwyn Harnisch, University of Illinois, Champaign, IL  
 Dr. Letz F. Hornke, Universitat Dusseldorf, Dusseldorf, W Germany  
 Dr. Paul Borst, Chula Vista, CA  
 Dr. Lloyd Humphreys, University of Illinois, Champaign, IL  
 Dr. Earl Hunt, University of Washington, Seattle, WA  
 Dr. Huynh Hayn, University of South Carolina, Columbia, SC  
 Dr. Douglas Jones, Advanced Statistical Technologies, Lawrenceville, NY  
 Dr. Marcel Just, Carnegie-Mellon University, Pittsburgh, PA  
 Dr. Demetrios Karis, University of Illinois, Champaign, IL  
 Dr. Scott Kelso, Mankins Laboratories, New Haven, CT  
 Dr. William Koch, University of Texas-Austin, Austin, TX  
 Dr. Stephen Koslany, Harvard University, Cambridge, MA  
 Dr. Thomas Leonard, University of Iowa, Iowa City, IA  
 Dr. Michael Levine, University of Illinois, Champaign, IL  
 Dr. Robert Linn, University of Illinois, Urbana, IL

Dr. Frederic M. Lord, Educational Testing Service, Princeton, NJ  
 Dr. Don Lyon, Higley, AZ  
 Dr. Gary Marco, Educational Testing Service, Princeton, NJ  
 Dr. Jay McLelland, MIT, Cambridge, MA  
 Dr. Robert McKinley, American College Testing Programs, Iowa City, IA  
 Dr. Barbara Means, Human Resources Research Org., Alexandria, VA  
 Dr. Robert Mashev, Geneva, IL  
 Dr. M. Alan Nicewander, University of Oklahoma, Oklahoma City, OK  
 Dr. Melvin R. Novick, University of Iowa, Iowa City, IA  
 Dr. James Olson, HCAT, Orem, UT  
 Dr. James Paulson, Portland State University, Portland, OR  
 Dr. James M. Pellegrino, University of California, Santa Barbara, CA  
 Dr. Mike Posner, University of Oregon, Eugene, OR  
 Dr. Mark D. Reckase, ACT, Iowa City, IA  
 Dr. David Ruelhart, University of California-San Diego, La Jolla, CA  
 Dr. Prof. Fumiko Samejima, University of Tennessee, Knoxville, TN  
 Dr. Arthur Samuel, Yale University, New Haven, CT  
 Dr. H. Wallace Sinaiko, Smithsonian Institution, Alexandria, VA  
 Dr. Martha Stocking, Educational Testing Service, Princeton, NJ  
 Dr. Peter Stolfoff, Center for Naval Analysis, Alexandria, VA  
 Dr. William Stout, University of Illinois, Urbana, IL  
 Dr. Kihumi Tatsuoka, CERL, Urbana, IL  
 Dr. Maurice Tatsuoka, University of Illinois, Champaign, IL  
 Dr. David Thiessen, University of Kansas, Lawrence, KS  
 Dr. Gary Thomason, University of Illinois, Champaign, IL  
 Dr. Robert Tuckman, University of Missouri, Columbia, MO  
 Dr. Ledyard Tucker, University of Illinois, Champaign, IL  
 Dr. Howard Wainer, Educational Testing Service, Princeton, NJ  
 Dr. Ming-Mei Wang, University of Iowa, Iowa City, IA  
 Dr. Brian Waters, HumRO, Alexandria, VA  
 Wolfgang Wiedegrupe, German Military Representative, Washington, DC  
 Dr. Bruce Williams, University of Illinois, Urbana, IL  
 Dr. Marilyn Wingersky, Educational Testing Service, Princeton, NJ  
 Dr. George Wong, Memorial Sloan-Kettering Cancer Ctr, New York, NY

**END**

**FILMED**

**10-84**

**DTIC**