DOCUMENT RESUME

ED 313 454 TM 014 314

AUTHOR	Ackerman, Phillip L.
TITLE	Individual Differences in Learning and Cognitive Abilities. Final Report.
INSTITUTION	Minnesota Univ., Minneapolis.
SPONS AGENCY	Office of Naval Research, Arlington, Va.
PUB DATE	15 Sep 89
CONTRACT	N00014-86-K-0478
NOTE	81p.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC04 Plus Postage.
DESCRIPTORS	Air Traffic Control; *Cognitive Ability; Computer Simulation; *Federal Programs; *Individual Differences; *Learning Processes; Performance; *Research Projects; Research Reports; *Skill Development
IDENTIFIERS	*Empirical Research

ABSTRACT

This final report reviews a program of theoretical and empirical research focusing on the ability determinants of individual differences in skill acquisition. An integrative framework for information processing and cognitive ability determinants of skills is presented, along with principles for ability-skill relations. Three major patterns of individual differences in skill acquisition are considered: (1) changes in between-subject variability; (2) the simplex pattern of trial intercorrelations; and (3) changing ability-performance correlations with practice. In addition to a review of previous theory and data, experimental manipulations are used to evaluate the cognitive ability demands associated with information processing parameters of skilled performance. A complex air traffic controller simulation task used in several investigations is introduced, along with empirical tests of theoretical principles. Examinations of practice-related between-subject variance changes and ability-performance correlations are used to demonstrate that an equivalence exists between three broad phases of skill acquisition and three cognitive/intellectual ability determinants of individual differences. Recent extrapolation of the theory to a dynamic representation of abilities is reviewed. Abstracts of scientific publications associated with the research are appended. (Author/TJH)

Final Report

Contract N00014-86-K-0478

Individual Differences in Learning and Cognitive Abilities

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University of Minnesota

The research summarized in this report was sponsored by the Cognitive Science Program, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-86-K-0478, Contract Authority Identification Number, NR 4422-543.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704 0188

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release: distribution unlimited
4 PERFORMING ORGANIZATION REPORT NUMBER(S) Report 89-01	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION University of Minnesota 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Cognitive Science Program (Code 1142CS) Office of Naval Research
6c ADDRESS (City, State, and ZIP Code) Elliott Hall, 75 East River Rd Minneapolis, MN	7b ADDRESS (City, State and ZIP Code) 800 North Quincy Street Arlington, VA 22217-5000
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-K-0478
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO 61153N; PROJECT NO RR04206; TASK NO RR04206-01; WORK UNIT ACCESSION NO NR4422-543

11 TITLE (Include Security Classification)

Individual Differences in Learning and Cognitive Abilities (unclassified)

12 PERSONAL AUTHOR(S)

Ackerman, Phillip L.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final Report	FROM 8/1/86 TO 7/31/89	1989-September-15	67

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Learning, individual differences, cognitive abilities, intelligence, skill acquisition, perceptual speed, information processing
05	09		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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(continued on reverse)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Dr. Susan Chipman	22b TELEPHONE (Include Area Code) 202-696-4318 22c OFFICE SYMBOL ONR1142CS

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 Unclassified

19. ABSTRACT continued

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PART I. REVIEW OF THE CURRENT RESEARCH PROGRAM

The broad goals of this research program have been to ultimately answer the following questions: (1) Under what learning conditions do individuals converge (i.e., become more alike) in skill and knowledge acquisition, versus under what conditions do initial individual differences remain stable or become exacerbated (i.e., when high-ability and low-ability learners diverge in performance)? (2) How do individual differences in general and specific cognitive abilities affect a learner's initial strategies when confronting a new learning opportunity? (3) Ordinarily, general cognitive abilities are strongly correlated with acquisition of novel perceptual-motor skills, but much less correlated with final level of expertise after task practice. What learning task parameters must be altered to allow lower-ability learners to achieve better footing <u>early</u> in training? (4) Is it possible to identify the class of learners that show poor performance early in learning, but ultimately acquire skills equivalent to learners with high abilities?

Domain

Adams (1987), in a recent review of human motor skills research, has emphasized the need to establish a working definition of motor skills. For the treatment of skill acquisition in this report, Adams' defining criteria will be used: "(1) Skill is a wide behavioral domain. (2) Skill is learned. (3) Goal attainment is importantly dependent upon motor behavior. (p.7)" More details are provided in the Adams article, but these three criteria subsume the domain considered here. Types of tasks that fall under this rubric include operating simple machinery, aspects of driving a car, technical aspects of playing musical instruments, and so on. Excluded from this domain are a variety of *non-motor* learned behaviors, such as chess mastery, physics problem solving, and analogical reasoning (see Sternberg [1985] for a discussion of such issues).

Individual Differences During Skill Acquisition

Previous theories of individual differences in learning have examined: (1) changes in between-subject variability, (2) the simplex structure, and (3) changing ability-performance intercorrelations. These theories and phenomena will be discussed in turn below.

<u>Between-Subject Variability</u>

E. L. Thorndike (1908) posed the question as to whether individuals converge in level of performance (i.e., a drop in variability) or diverge (i.e., an increase in variability) with task training. No final resolution was reached during this period, and interest in the topic generally waned after the 1930's.

Ackerman (1987) performed a limited reanalysis of the earlier practice and variability data. There were two major difficulties with the literature. First, the common measure of variability used today, the standard deviation (σ), is a relatively recently adopted statistical tool in psychology. Well into the 1930's researchers used many different variability measures that were confounded to varying degrees with mean [μ] performance level (such as mean variability -- $\hat{\mu}/\hat{\sigma}^2$). The second difficulty was that some investigators used measures that assessed performance in terms of

attainment, that is, the number of problems completed in a fixed period of time, while other investigators assessed performance in terms of *speed* or *reaction time* (RT) that is, the time taken to complete one item. Although attainment and RT are merely reciprocals of one another, uniform changes due to learning for an attainment measure will bring about changes in variability of an RT measure.

Recent theories of skill acquisition and information processing (Anderson, 1982, 1983; Newell & Rosenbloom, 1981) provide a theoretical and empirical framework that depends on the RT metric. When the earlier data are transformed to RT measures, the effects of practice on variability are conclusive. In a review of 24 short skill acquisition experiments (practice ranging from 9-200 minutes total time-on-task), Ackerman (1987) found that between-subjects $\hat{\sigma}$ were clearly reduced after practice, an average of 34% from initial levels. Thus, when initial tasks are within the abilities of the respondents, inter-individual *variability of performance decreases with practice*. This finding, however is not universal. Task complexity affects both the initial level of variability and the rate of attenuation with practice. Task consistency is also important. Performance variability decreases *only* when the information processing requirements are predominantly "consistent," such as when subjects deal with particular stimuli in the same manner over repetitive tasks (see, e.g., Shiffrin & Schneider, 1977). When the task configuration precludes the development of automatic processing, RT variability remains constant (or may increase) over practice, even when mean RT decreases (Ackerman, 1986, 1987).

Simplex

A fundamental and ubiquitous finding in the study of inter-individual differences over task practice is the *quasi-simplex* (or superdiagonal) pattern of intertrial intercorrelations (Humphreys, 1960). The characteristic quasi-simplex pattern of correlations is for the largest values to occur in adjacent task trials, and for a decline in correlations as the trials become more distant from one another (i.e., the lowest value will correspond to the correlation between the first and last trial). The implication from this pattern of practice intercorrelations is that individuals continuously change their rank order, indicating that the underlying determinants of performance also change during practice. So far, the *specific* causes of these changes have not been successfully identified. Yet, much theoretical discussion has been devoted to the ability determinants of performance (e.g., Alvares & Hulin, 1972; Corballis, 1965; Jones, 1962, 1970).

Analysis of the patterns of trial-by-trial intercorrelations has (if not extensively) identified two particular skill acquisition characteristics (Ackerman, 1987; Jones, 1970; Reynolds, 1952a, 1952b): the rate of correlation attenuation (i.e., the rate of decline in correlation between initial [or early] task performance and each additional set of trials), and the rate of change in adjacent correlations with practice (i.e., changes in stability of individual differences in performance). A few extreme examples (where the use of false performance feedback was used) have indicated that such parameters of intertrial correlations can indeed be altered (Jones, 1970, 1980). However, the present thesis is that rate of attenuation and rate of change in adjacent correlations are generally less sensitive than ability-performance correlations to changes in task information processing demands.

Ability-Performance Correlations

Briefly, there are few studies that have examined the association between performance levels during task practice and reference cognitive abilities. Fleishman and his colleagues have claimed three basic principles for ability-performance relations: (1) Broad cognitive abilities determine initial task performance; (2) perceptual/motor abilities increasingly determine performance later in practice; and (3) Some new, task-specific ability develops with practice that differs from both the cognitive and perceptual/motor abilities (Fleishman, 1972; Fleishman & Quaintance, 1984). Increasingly influential task-specific factors have been core notions of more than one currently popular theory of individual differences in skill acquisition (e.g., Fleishman & Quaintance, 1984; Jones, 1970; Kleinman, 1977; for critical discussions of this issue, see Ackerman, 1987; Adams, 1987).

For a sample of simple, consistent tasks, the first two general findings by Fleishman, et al. have been partly substantiated. That is, broad intellectual abilities appear to correlate substantially with initial task performance, but these correlations diminish as skills are acquired. Further, some perceptual/motor abilities, that initially show small correlations with performance increase during practice. However, methodological reports (e.g., Humphreys, 1960) have demonstrated that joint factoring of ability and practice data (often used by Fleishman and his colleagues) brings about spurious late-appearing task-specific factors. Thus, even Fleishman's own data, when reanalyzed with modern statistical techniques *fail* to support the third principle, relating to new task-specific abilities (Ackerman, 1987).

A recent investigation (Ackerman, 1986) has further demonstrated that information processing *consistency* moderates the relations between particular abilities and performance during skill acquisition. That is, when tasks differ in consistency, general and broad ability-performance correlations are higher for the tasks with a lower degree of consistency.

In summary, the three major factors that have thus far thwarted the search for general laws relating cognitive abilities to skill acquisition are: (1) the lack of a common metric for performance across studies, (2) the lack of higher order ability data, and finally, (3) the paucity of data relating cognitive abilities to task performance.

A Skill Acquisition Foundation

A review of the skill acquisition literature lies beyond the scope of this report (though see Fitts & Posner, 1967; Adams, 1987; Anderson, 1982, 1983; Schneider & Shiffrin, 1977). However, from the early studies of Bryan & Harter (1899), Book (1910), the theories of William James (1890) and others, some fundamental characteristics of skill acquisition have been established. Converging delineations have been offered over the last few decades. Fitts (1964, Fitts & Posner, 1967) suggested that, from a cognitive information processing perspective, skill acquisition can be segmented into three phases: "Cognitive" (Phase 1), followed by "Associative" (Phase 2), finally, "Autonomous" (Phase 3). More recent production system models of learning, for example, by Anderson (1982, 1983) term these phases as (1) Declarative Stage, (2) Knowledge Compilation, and (3) Procedural Stage, and in a more empirical framework (Shiffrin & Schneider, 1977; Schneider & Shiffrin, 1977), they are labelled (1) Controlled Processing, (2) Mixed Controlled and Automatic Processing, and (3)

Automatic Processing. Despite the varying terminology, the underlying processes at each skill acquisition phase are qualitatively identical (and, by and large, quantitatively identical - for the Anderson and Schneider & Shiffrin approaches; see Anderson, 1983).

Initial confrontation with a skill-acquisition task (assuming that the information processing requirements are relatively novel) involves a strong demand on the cognitive-attentional system. During this phase, performance is slow and error-prone, while strategies (productions) are formulated and tested, and attention is primarily given to understanding and performing the task in question. With *consistent* practice (as described by Schneider & Shiffrin, 1977), performance speed and accuracy increase markedly and attentional demands are reduced (Fisk & Schneider, 1983). The productions needed to accurately perform the task are fully formulated. During this second stage (Phase 2), the stimulus-response connections of the skill are refined and strengthened. Ultimately, the final stage of performance is best characterized as "autonomous" or "automatic" (Phase 3). Consistent practice results in fast and accurate performance; the task can often be completed competently even when attention is simultaneously devoted to other tasks (e.g., Schneider & Fisk, 1982a). Practice at this stage yields diminishing returns, in keeping with the Power Law of Practice (Newell & Rosenbloom, 1981).

Normative and Differential Mappings

From the evidence reported to date, several explicit linkages between normative and individual differences in skill acquisition phenomena may be drawn. Specifically:

(1) Skill acquisition is generally described as a continuous process during task practice, without breaks as processing transitions from Phase 1 through Phase 3. The individual differences description of skill acquisition (from trial intercorrelations) indicates that rank orderings of subjects change, also in a continuous process, without breaks during task practice (i.e., the quasi-simplex structure).

(2) During skill acquisition, load on cognitive processes declines from novice attention-demanding processing to skilled automatic processing. Initial ability- performance associations are higher for more general cognitive abilities. After consistent practice, these abilities show attenuated correlations.

(3) The presence of inconsistent information processing task demands slows, or altogether precludes, the development of Phase 2 and Phase 3 skill levels, tha s, the task remains attention-dependent. Similarly, inconsistent information-processing demands perpetuate the cognitive ability-performance associations over task practice.

Based on evaluation of the range and types of processes underlying the three phases of skill acquisition, and the individual differences data described above, a parsimonious linkage of three major ability factors to skill acquisition phases is possible. These three factors are general intelligence (or general ability), perceptual speed, and psychomotor ability. Descriptions and definitions of these abilities are provided below.

Abilities Underlying Skill Acquisition

General Intelligence (General Ability)

A general cognitive/intellectual ability is implied by the variance common to the universe of all psychological ability tests. Such an ability is often found to account for about 50% of the individual differences variance on large batteries of ability tests (Vernon, 1961). The inference is that the general ability represents a broad construct that underlies non-specific information processing efficacy (i.e., it excludes specific types of processing individual differences that are mostly associated with separable abilities, such as dealing with verbal, figural, or numerical item content). For example, the reasoning processes that account for individual differences across different content domains would represent one component of a general intellectual ability.

Humphreys (1979) summarizes the construct: "*[General] intelligence is the resultant of the processes of acquiring, storing in memory, retrieving, combining, comparing, and using in new contexts information and conceptual skills....*" In this view general intelligence *must* be a determinant of individual differences in the processes that are described as underlying Phase 1 of skill acquisition. In fact, there appears to be a monotonically increasing association between the attentional demands of the task and performance correlations with some general intellectual ability factor (Ackerman, 1986, 1988; Kyllonen, 1987; Sternberg, 1977). These attentional demand effects can also be seen in the changes of working memory capacity correlations with individual differences in task performance over practice (Kyllonen & Woltz, 1989; Woltz, 1988).

Perceptual Speed Ability

Two contrasting views of perceptual speed ability represent the general orientation of the field. One perspective (Marshalek, Lohman, & Snow, 1983) identifies a single major dimension of abilities, denoted level/speed. At one end of the continuum are abilities that are associated with an individual's facility in solving items of increasing complexity. At the other end of the continuum are abilities that are associated with the *speed* of processing. Perceptual speed is claimed to represent individual differences in the speed with which cognitive test items can be completed, when the domain only includes simple items.

The other, pragmatic, perspective depends on review of tests which cluster together along some general lines. This perspective suggests that perceptual speed is indeed an ability class that can be separated from the domain of spatial abilities (e.g., see Thurstone, 1944; Ekstrom, French, Harman, & Dermen, 1976; Lohman, 1979). This is an especially important demonstration, since the many prototypical tests designed to measure perceptual speed contain spatial content.

A wide range of tests have been posited to load on the perceptual speed ability. Marker tests include Finding x's or Finding a's (Thurstone, 1944; Ekstrom, et al., 1976) which entail searching through random letters or a list of words and identifying instances of the target letter. Another test is the Digit-Symbol test, which entails a paired-associates type of information processing -- that is, memorization (or rapid reference to a list) of a set of digit-symbol pairs and transcribing symbols on a list of digit probes. Many of these tests appear to involve the generation of very simple production systems that must be used to effectively solve the test items. In the

language of skill acquisition, *individual differences found on such tests are directly attributable to the speed with which these productions can be implemented and compiled* (e.g., see Werdelin & Stjernberg, 1969). Other conceptualizations of perceptual speed are possible, but the core concept appears to involve speed of consistent encoding and comparing symbols.

Psychomotor Ability

The psychomotor domain represents an amalgamation of a family of related -- but independently identifiable sub-abilities. A general psychomotor ability represents individual differences predominantly in the speed of responses to test items with little or no cognitive processing demands. Whereas the perceptual speed ability represents cognitive processing of generally simple (but still cognitively involving) items, psychomotor ability represents processing speed (and accuracy to a certain degree), mostly independent of information processing, per se.

Prototypical measures of psychomotor ability include Simple Reaction Time, Rotary Pursuit, Tapping Speed, Rate of Manipulation, Finger Dexterity, and so on (Fleishman, 1954). While some of these tests require minimal information processing (mostly in terms of sensory feedback), the underlying characteristic of these tests is that *the examinee knows exactly what responses need to be made, ahead of time.* Psychomotor ability can be defined as representing individual differences in the speed (and accuracy) of motor responding that are characteristic of psychophysical limitations of the human subject. That is, the underlying differentiating processes of psychomotor ability are those that reveal the efficacy of *asymptotically* compiled and tuned production systems.

Representation of Abilities

Many representations of cognitive/intellectual abilities that allow for linkage with types of information processing have been offered in the literature. Some are essentially piecemeal mappings of abilities with information processing paradigms (Carroll, 1980), while others are general, all encompassing theories of abilities and information processing (e.g., Sternberg, 1985). In order to allow for an empirically-based mapping of abilities to information processing skills, an intermediate approach is required.

Modern ability theories are often categorized as hierarchical in nature, with the general ability defining the highest level node in the hierarchy. Major group factors (such as verbal, spatial, number, etc.) are located at lower nodes in the hierarchy, and specific abilities at still lower nodes (Vernon, 1961). For present purposes, a functionally equivalent (and more parsimonious) representation of the major components of intellectual abilities is the radex (Marshalek, et al., 1983).

Problems exist in locating perceptual speed or psychomotor abilities in the Marshalek et al. (1983) model. Representation of these abilities can be rectified by explicitly segregating the complexity/specificity dimension from one of level/speed. With this modification, a third dimension will allow for both perceptual speed and psychomotor abilities. Using the basic two-dimensional surface at the extreme on the power (level)-speed dimension (i.e., a zero value for speededness of information processing demands), and an arbitrary value representing the extreme in speededness (with the absence of cognitive processing -- i.e., non-cognitive motor speed), the

structure of human abilities can be represented as a cylinder, as idealized in Figure 1. Theoretically, as one moves down the cylinder, concentric sections represent the basic cognitive ability groups, with increasing demands on speededness

Snow, Kyllonen, & Marshalek (1984) have demonstrated support for the two dimensional radex version from several data sets in the literature, although such data sets do not contain a substantial sampling of highly speeded tests. In addition to the logical consistency of the revised model, data exist that clearly support the current model. An example of such data is reported in Figures 2 and 3. The figures illustrate a non-metric multidimensional scaling of data (from 315 Naval recruits) initially reported by Allison (1960). The tests re-analyzed here were from a reference test battery of 37 variables. A small number of variables (6) were excluded from the analysis detailed in these figures: these measures were four memory tests, Cubes, and Steadiness. The memory tests were excluded because it was not clear how speeded such tests were (given a rapid presentation speed, but a longer free-response period). The Cubes and Steadiness tests were excluded as a result of extremely low communality estimat .. (Analysis of the total reference battery produced no significant deviations from the current results; however, reducing the battery resulted in a somewhat clearer spacial representation)

The multidimensional scaling results in three dimensions (as specified by the model) were rotated to principal components, and *no* attempt was made to maximize fit of the data to the current model. Nonetheless, the results clearly support the model. Dimension 1 (see Figure 2) is obviously a contrast between level and speed. Complex power tests such as Letter Sets and Reasoning provide the anchors for the level tests, moderately speeded tests i.e., perceptual speed tests) such as Word Checking, Addition, and Clerical Aptitude define the middle portion of the dimension, and highly speeded tests (i.e., psychomotor ability tests) such as Turning, Placing, and Writing X's define the Speed anchors of the dimension.

Dimensions 2 and 3 (see Figure 3) also support the complexity-content radex postulated by Marshalek, et al. (1983), which are incorporated into the present model. That is, highly complex tests that define general intelligence are located in the center of the structure, with content abilities in the surrounding quadrants. Further details of this reanalysis may be found in Ackerman (1988). These results offer convincing evidence supporting the current model of reference abilities for skill acquisition.

Integrative Principles

With the description of skill acquisition on the one hand and the model of cognitive abilities on the other, it is possible to explicitly provide three principles of individual differences in skill acquisition.

Principle 1

Skill acquisition Phase 1 corresponds to demands on general (and content abilities).

With a mapping of general ability with Phase 1, the theoretical representation of the associations of ability and performance is given in Figure 4, Panel A. The standard task for this representation is of moderate complexity, and is consistent (a typical skill

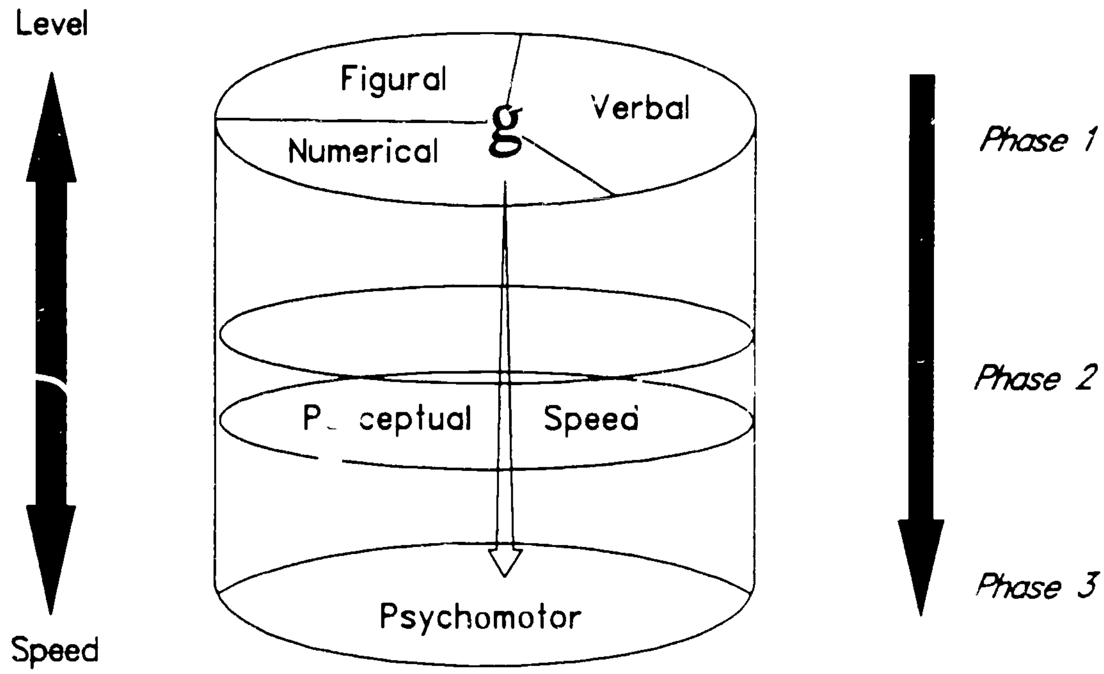

Figure 1. A modified radex-based model of cognitive abilities. Complexity is represented as in the Marshalek, et al. model. However, the dimension of level/speed is added to represent perceptual speed and psychomotor abilities. (From Ackerman, 1988. Copyright American Psychological Association.)

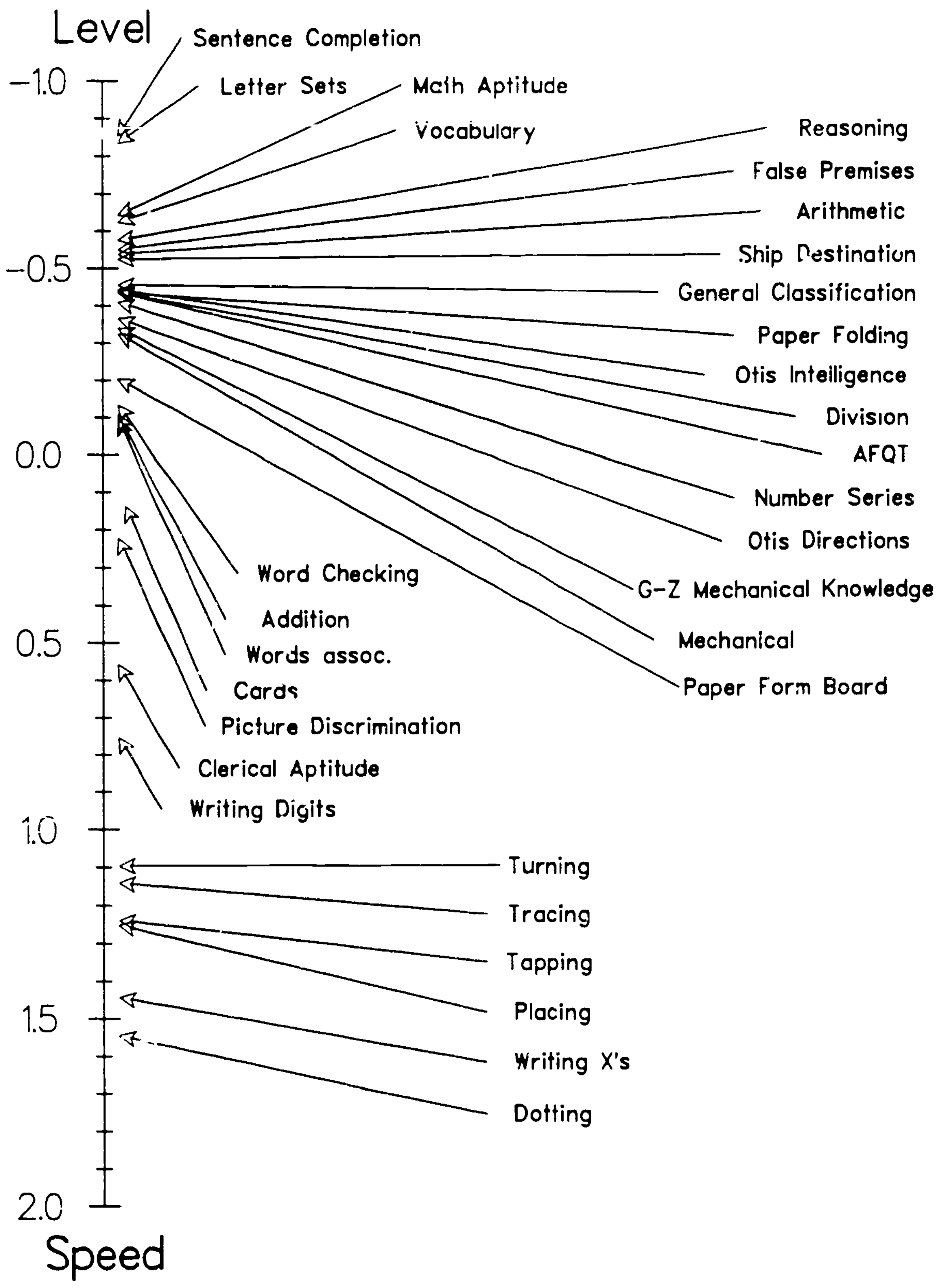

Figure 2. Mapping of 31 reference test variables on Dimension 1. From multidimensional scaling reanalysis of Allison (1960) data. The dimension is identified as level vs. speed. (From Ackerman, 1988. Copyright American Psychological Association.)

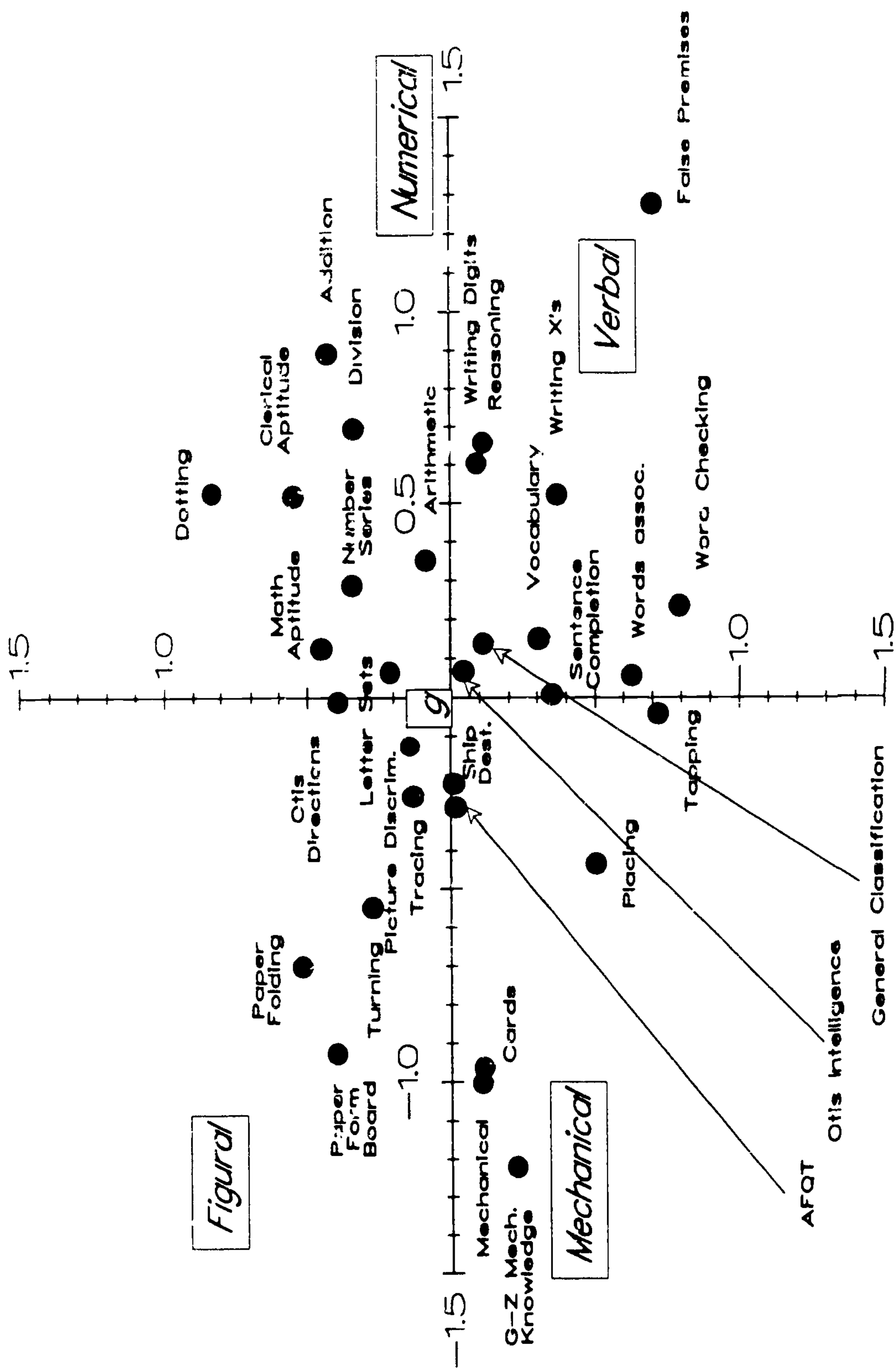

Figure 3. Mapping of 31 reference test variables on Dimensions 2 and 3. From multidimensional scaling reanalysis of Allison (1960) data. Dimensions 2 and 3 identify the radex complexity-content structure as identified by Marshalek, et al. (1983), and incorporated in the current three-dimensional model of abilities. (From Ackerman, 1988. Copyright American Psychological Association.)

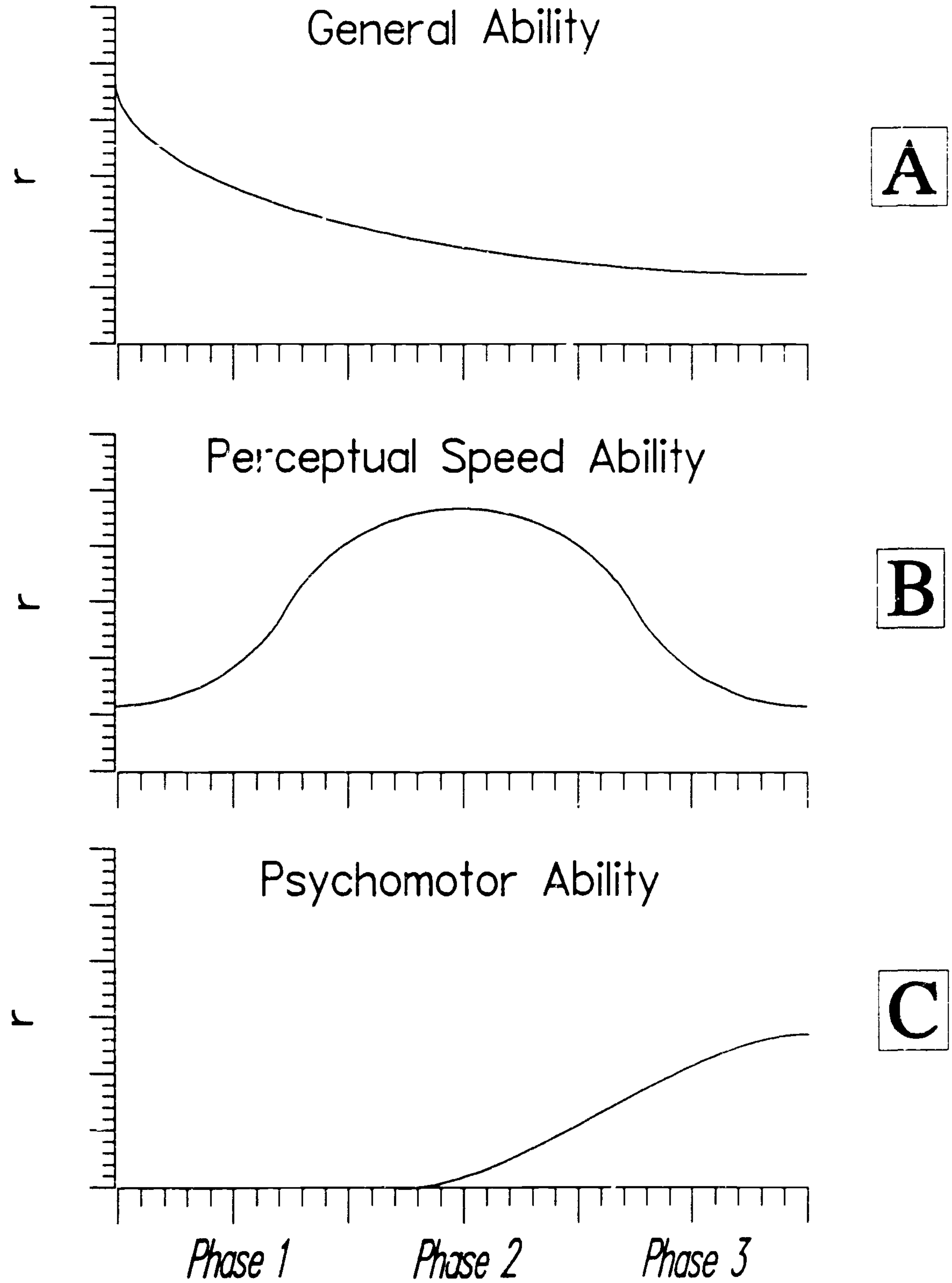

Figure 4. Hypothetical ability-skill relations derived from the f amework. The hypothetical task is moderately complex, involves a moderate amount of broad trans-- and provides for consistent information processing. (From Ackermar Copyright American Psychological Association.)

acquisition task). Initial performance individual differences will be moderately-to-highly associated with the general ability. With practice (as Phase 1 transitions into Phase 2), the ability-performance association will attenuate, reaching an asymptote late in practice.

Depending on the task content, initial performance individual differences will be determined to some degree by task-appropriate broad content abilities (e.g., verbal abilities for tasks that demand processing of semantic material; spatial abilities for tasks that demand figural processing, etc.). The overall magnitude of association of these abilities with performance will depend on task complexity (see below), but also on the adequacy of instructions, and, of course, on the subject population under study. With practice, once production systems are formulated to accomplish the *consistent* components of the task, the influence of general/content abilities will diminish.

Principle 2

Skill acquisition Phase 2 corresponds to demands on perceptual speed ability.

If perceptual speed reflects the processes involved in compilation of production systems, there will be an inverted U-shaped function which describes ability-performance relations over practice (see Figure 4, Panel B). Early in practice, the productions are still being formulated and tested, thus compilation and tuning are only involved to the degree that previously learned productions can be readily adapted for successful performance of the current task. Therefore, once the productions are formulated there is an initially increasing association between perceptual speed ability and performance. Perceptual speed ability, that is, the facility and speed of compilation of production systems that determine performance efficiency is the essence of Phase 2. However, as learners reach their psychophysical limitations of skilled performance, the influence of this variable will attenuate (i.e., as Phase 2 transitions to Phase 3). As Phase 3 and asymptotic performance levels are reached, perceptual speed will further decline to some asymptotic level.

Principle 3

Skill acquisition Phase 3 corresponds to predominantly non-cognitive psychomotor abilities.

For skill acquisition tasks which allow successful performance across a wide range of ability, asymptotic task performance individual differences will be more dependent on non-cognitive motor abilities than cognitive abilities. That is, as cognitive abilities no longer serve to limit performance, individuals converge on performance asymptotes that are finally determined by (non-cognitive) psychomotor speed differences (e.g., as in cigar-rolling or choice RT tasks, see Newell & Rosenbloom, 1981). Even so, the actual performance differences between the fastest and slowest learners at this level of skill development are vastly reduced. That is, standard deviations of performance are reduced with consistent practice.

Therefore, as Phase 2 gives way to Phase 3, psychomotor variables will increase in association with performance, ultimately stabilizing to a moderate degree of correlation. It follows, then, that the theoretical predictions of psychomotor ability-performance relations are as illustrated in Figure 4, Panel C. During Phase 1 and 2 of skill

acquisition, psychomotor speed has an inconsequential influence on performance. However, as Phase 2 transitions to Phase 3, whatever information processing productions there are have been formulated, compiled, and are being finally tuned. Asymptotic performance, when little or no new information must be processed from trial-to-trial, will be associated with individual differences in psychomotor ability.

Representation of Abilities and Skills

The theory of ability-skill relations states that complex, novel tasks tap abilities located towards the top of the cylinder (in Figure 1). Thus, task performance early in practice will have high correlations with content and general abilities, relatively low correlations with perceptual speed ability, and negligible correlations with psychomotor ability. At intermediate levels of practice, association with broad content and general abilities declines, association with perceptual speed ability increases. Ultimately, even associations with perceptual speed decline, as individual differences in asymptotic performance are determined by psychomotor ability.

Two Moderating Variables

Complexity. Common complexity manipulations include altering memory load, display load (number of items), number of response choices, display duration, number of intermediate results necessary to solution, amount of stimulus-response (S-R) compatibility, amount of information provided to the learner, and many others. While each of these paradigms impose somewhat different requirements on the learner, there is more than minimal underlying commonality for these effects. Generally, changes in these variables affect the amount of attention demanded by the task, the accuracy with which the learner can perform the task, and/or the amount of time to complete a trial.

Manipulation of task complexity is predicted to bring about an inverse relationship between general ability-performance and perceptual speed-performance associations for Phase 1 and Phase 2. Task complexity effects a tradeoff between the dependence of performance on general abilities and perceptual speed abilities. For example, when S-R compatibility is high, there is less cognitive demand on the learner to determine and initiate the appropriate response. Thus, for tasks that differ in complexity there will be a negative association between initial ability-performance loadings on general/broad cognitive factors and perceptual speed factors.

Consistency. Task consistency has been found to have a strong moderating influence on skill acquisition during practice (e.g., Fisk & Schneider, 1983). As such, this construct must be included in any integrated theory for individual differences in skill acquisition. Consistency, *ceteris paribus*, does not have direct impact on the *initial* demands of the criterion task. When the tasks are novel, learners confronting both predominantly consistent and predominantly inconsistent tasks begin at Phase 1 (controlled processing). With practice, though, consistent tasks allow for skill acquisition, while inconsistent tasks generally do not. Rather, inconsistent tasks remain cognitively involving (Phase 1) over long periods of practice.

The contrast to the prototypical skill acquisition situation occurs when the task requires a moderate or substantial degree of inconsistent information processing. Performance individual differences on tasks with substantial inconsistency remain dominated by the Phase 1, cognitive-controlled type of information processing (i.e.,

general ability). In the limiting case, individual differences on a task with no consistent components will show no reduction of association with general ability over practice, since a new set of productions must be formulated on every trial. The experimental psychology data indicate that each increment in the number of inconsistent information requirements raises the level of controlled processing demands (Schneider & Fisk, 1982b). That is, if consistency is provided, skill acquisition will proceed along the normal route. However, each instance of inconsistency will (a) require controlled processing, and (b) decrement the strength of the learned associations. The implied effects are illustrated in Figure 5. In accordance with the general ability-performance relations (Panel A), changes in degree of consistency will moderate the asymptotic levels of association between perceptual speed and performance (Panel B), as well as *when* the transition to Phase 3 will occur (Panel C).

Other Influences

There are other important sources of individual differences in skilled performance after substantial consistent task practice. One source, motivation, will not be considered here (though see Kanfer, 1987; Kanfer & Ackerman, 1989). The second and third influences relate to the efficacy of the initial productions formulated in Phase 1 of the skill acquisition process (a function of general/broad content abilities), and to the learner's ability to develop efficient and accurate compilation/tuning of the productions (perceptual speed and psychomotor abilities), respectively. The involvement of the latter two influences (and the first, to the degree that motivation and abilities are related) guarantees that performance individual differences will maintain association with cognitive abilities, even at extended levels of practice. Differences between learners who fail to develop automaticity will remain associated with these abilities.

Summary

Several contrasts may be drawn between the current theory and those previously discussed in the literature.

(1) In contrast to claims of ubiquitous divergence or ubiquitous convergence of individual differences with task practice, the theory predicts that changes in variability crucially depend on the consistency of the task information processing demands. When the task is consistent, variability declines as the general ability declines in influence. When the task has a substantial degree of inconsistent information processing demands, though, variability is predicted to remain stable (as general ability-performance relations do so).

(2) In opposition to Fleishman, et al. (Fleishman & Quaintance, 1984) the theory predicts that perceptual speed-performance correlations do not uniformly increase with task practice. Rather, for the late phases of skill acquisition, such correlations are expected to decline. In addition, the current theory makes an explicit distinction between the roles of perceptual speed and psychomotor abilities that is not made in the Fleishman theory.

(3) In contrast to the Jones (1970) two-process theory, the current theory states that there are *three* individual differences determinants of skilled performance. One of the determinants (perceptual speed) both increases and decreases in influence during the

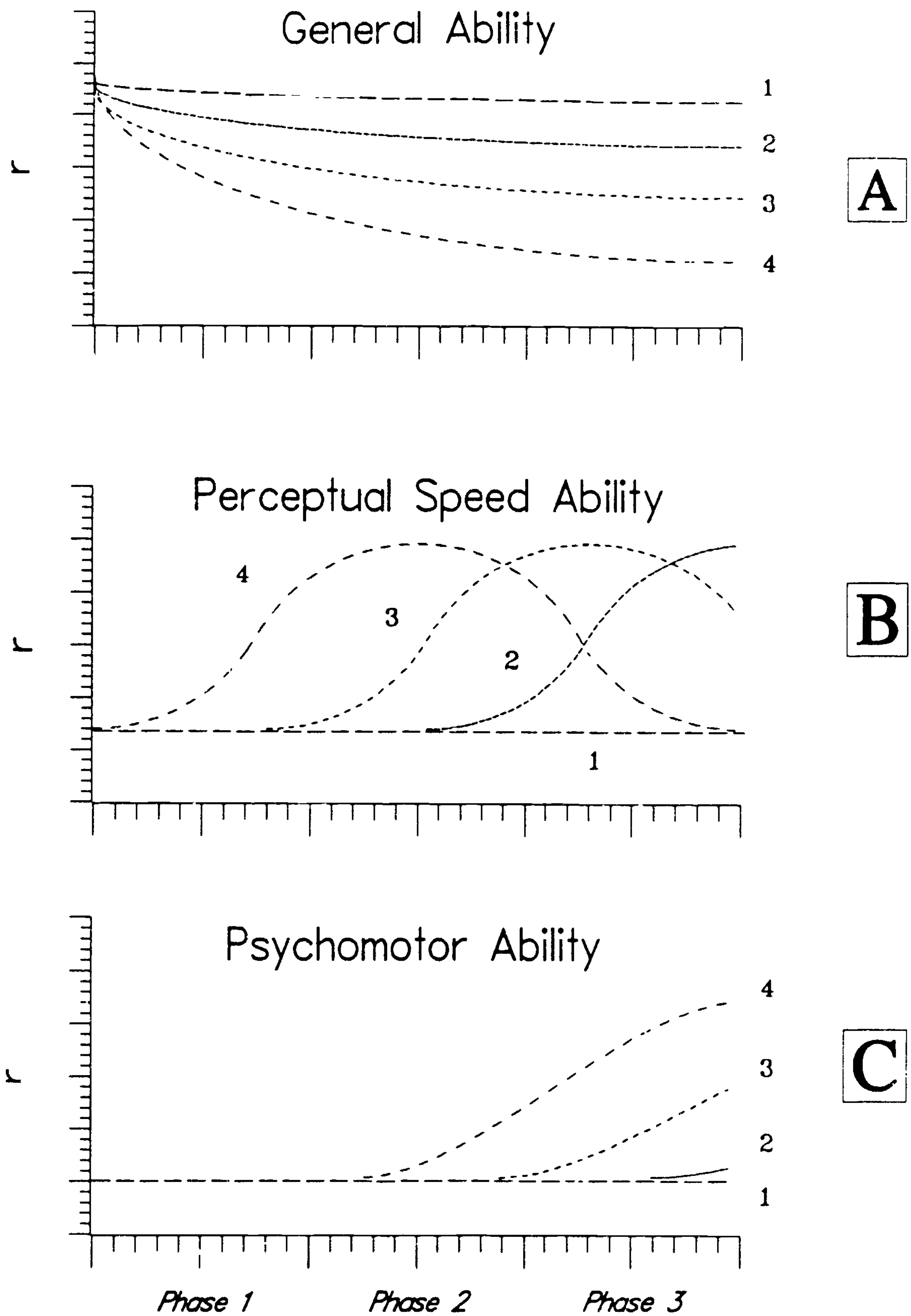

Figure 5. Idealized effects of consistency manipulations. Changes in degree of consistency result in changes in level of asymptotic ability-skill associations. Curve #1 -- No consistency; Curve #2 -- Moderate degree of consist cy; Curve #3 -- High degree of consistency; Curve #4 -- Completely consistent. (From Ackerman, 1988. Copyright American Psychological Association.)

course of skill acquisition, whereas Jones' determinants strictly decrease (rate) or strictly increase (terminal). Given that the current theory predicts changes in specific cognitive ability determinants of skill acquisition, it is consistent with the expectations for simplex-like trial intercorrelation matrices.

The current theory also ties together each of the three types of basic individual differences in skill acquisition data, whereas none of the other theories does so. In addition to these facets, the theory goes beyond the previous approaches in that it is grounded in skill acquisition theory and differential theory of cognitive ability structure. Most importantly, though, this theory allows explicit prediction of changes in ability-performance relations when task information processing constraints, such as complexity and consistency are manipulated.

PART III. EMPIRICAL VALIDATION OF THE THEORY:

Previous Data

An examination of psychomotor and perceptual speed ability associations with performance is provided by review of three studies in the literature which contain data adequate to address the issues. In particular, studies by Fleishman (1960, Fleishman & Hempel, 1954, 1955) allow a contrast between perceptual speed abilities and one major psychomotor ability factor (Rate of Arm Movement) for three tasks over practice. The tasks (Complex Coordination, Rotary Pursuit, and Discrimination RT), and procedures are described in detail elsewhere (see original references and reanalysis by Ackerman, 1987). It is important to emphasize that all three of these tasks are highly consistent, and essentially simple, from an information-processing perspective.

Predictions

Some methodological issues of the ability-performance relations for these data have been reported by Ackerman (1987), but the specific comparisons are provided here as illustrations of (a) the predicted decreasing correlations between perceptual speed and performance with practice, and (b) the predicted increasing correlations with psychomotor ability with practice.

Results

Figure 6 (Upper Panel) depicts the association between Perceptual Speed and performance for the three tasks. While the tasks are differentially dependent on Perceptual Speed at early levels of practice, all three follow the same predicted declining pattern of correlations expected when tasks are simple, and the initial association with general/content abilities is low. Figure 6, (Lower Panel) shows the analogous correlations between Rate of Arm Movement and performance over practice. As the current theory predicts, each of the three tasks shows an increasing association with this psychomotor ability as practice proceeds. Further, the initial and post-practice orderings of performance correlations on both abilities are in agreement with the theoretical predictions. That is, the substantially greater association of the Discrimination RT task with Perceptual Speed early in practice is associated with a later development of association between Rate of Arm Movement and performance. In accordance with the current theory, when tasks can be solved by simple productions (or already formed ones), as in the Complex Coordination and Rotary Pursuit tasks --

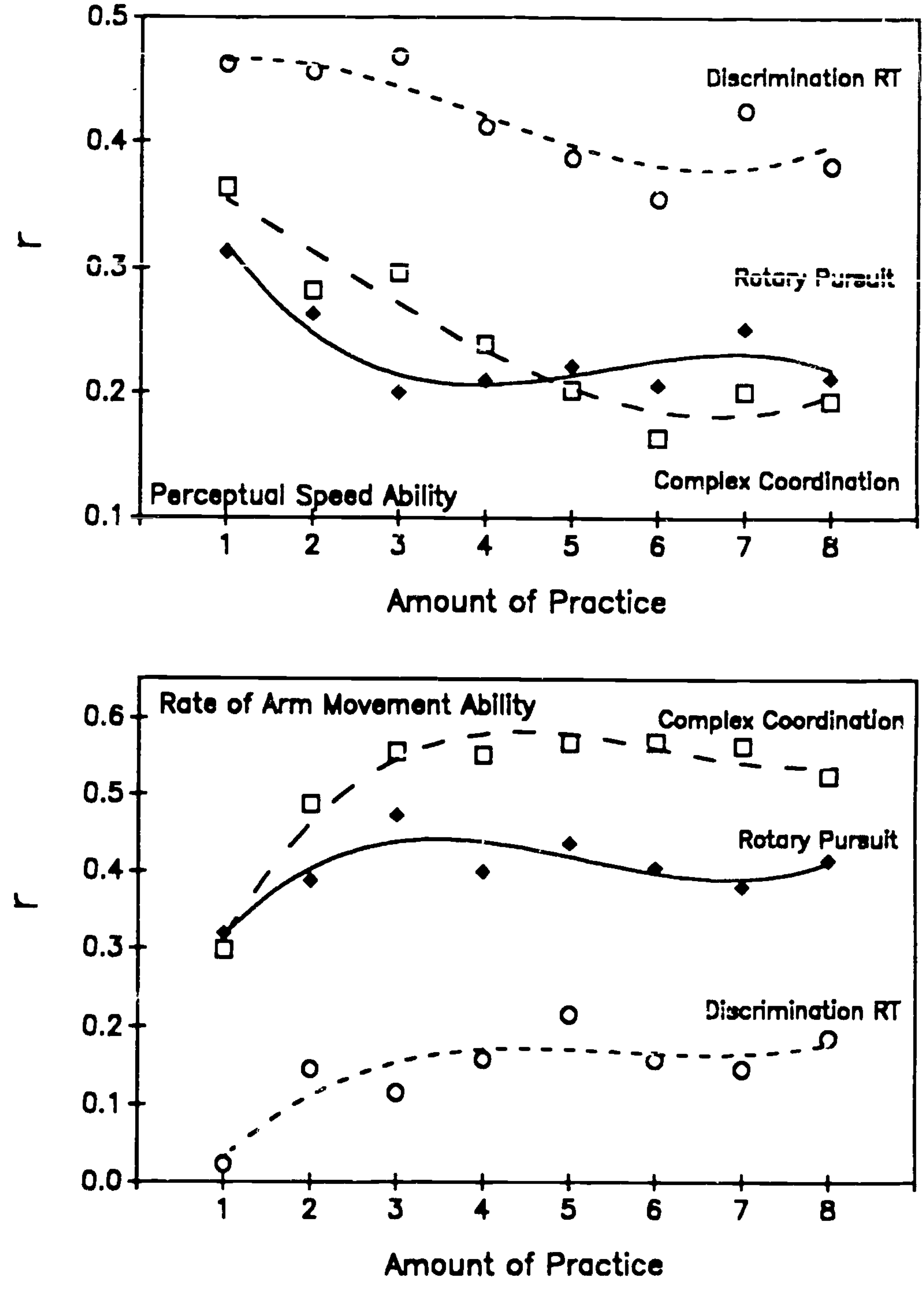

Figure 6. Ability-performance correlations for data compiled from Fleishman, et al. (Ackerman, 1987). **Upper Panel:** Correlations between derived Perceptual Speed ability and task performance. Lines indicate polynomial (cubic) regression of ability loadings over practice. **Lower Panel:** Correlations between derived psychomotor ability [Rate of Arm Movement] and task performance. Lines indicate polynomial (cubic) regression of ability loadings over practice. (From Ackerman, 1988. Copyright American Psychological Association.)

signaled by the lower correlations with Perceptual Speed -- psychomotor abilities become more important determinants of performance earlier in practice. The end result is a *reciprocal* relationship in the ability-performance correlations for perceptual speed and psychomotor abilities (e.g., as correlations between perceptual speed and performance decrease, correlations between psychomotor abilities and performance increase). While these data do not allow for a direct comparison of general/content abilities with performance, the overall results are consistent with the current theory.

Further evidence in support of this perspective can be found in the Complex Tracking data reported by Parker and Fleishman (1960). Although it has not been possible to reanalyze those data using current analytic techniques, the extended factor loadings reported by Parker and Fleishman show generally decreasing loadings of task performance on a broad Spatial Orientation factor, and generally increasing loadings of task performance on a psychomotor factor identified by the authors as "Multilimb Coordination."

Several experiments have provided parametric study of changing information processing parameters of memory load, novelty, and transfer (Ackerman, 1988). Two experiments are reported below that provide an evaluation of the theory at the level of a simple information processing task, and for a more complex task. Experiment 1 uses a nine-choice discrimination RT paradigm. Experiment 2 includes extensive measurement of ability factors, but the generalizability of the theory is also evaluated, through the use of an "Air Traffic Controller" simulation task.

Experiment 1

This experiment was conducted in order to obtain evidence concerning the predicted changes in psychomotor ability-performance correlations during skill acquisition, while further documenting the general ability- and perceptual speed-performance correlations predicted by the theory. The predictions for this task mirror the general theoretical predictions. Briefly, there are three predictions during skill acquisition: (1) decreasing correlations between general ability and performance; (2) increasing, then decreasing correlations between perceptual speed and performance; and (3) increasing correlations between psychomotor ability and performance.

Method

Subjects. One hundred (58 male, 42 female) students at the University of Minnesota participated in this experiment. The subjects were recruited from an introductory psychology course, and received both course credit and $12 for participating in the experiment (the experiment reported here was part of a larger study).

Apparatus. Task instructions, stimulus preparation, presentation, and response collection were performed with IBM PC computers, with standard keyboards and IBM monochrome display monitors. Ability tests were administered in two ways. Ten of the thirteen tests were administered at separate tables, using standard paper and pencil format. The three remaining tests (the Four-choice RT, Two-choice RT, and Simple RT tests), were administered on the computers.

Ability Tests. Thirteen ability tests were administered to the subjects. The tests

were selected to reveal four first order factors (Spatial, Perceptual Speed, Psychomotor [RT], and Verbal) and a single second-order General/Spatial ability factor.

Stimuli. Stimuli were two-letter abbreviations for the location of the number key (1-9) on the computer keyboard. The first letter in the abbreviation represented the vertical position of the key: "Lower Row," "Middle Row," or "Upper Row" (L, M, or U, respectively); the second letter in the abbreviation represented the horizontal position of the key: "Left," "Middle", or "Right" (L, M, or R respectively). (For example, "MM" = Middle Row - Middle Column = "5".)

Procedure. For each task trial, an "X" was initially presented in the center of the CRT for 0.5 sec (as a focusing reference). Immediately thereafter, the two-letter abbreviation for the number location was presented. The procedure was thus experimenter-paced, not subject paced. Subjects were told to respond to the number which corresponded to the two-letter position abbreviation of the screen. Subjects were further instructed that their goal was to maintain accuracy at the 90-95% correct range and to respond as fast as they could, holding that accuracy level. (This accuracy level was selected so as to minimize differential effects of speed-accuracy tradeoff on performance measures.) Finally, the subjects were told to rest their right hand index, middle, and ring fingers on buttons "4", "5", and "6" respectively.

After a subject's probe response was made (or a 5 sec wait time limit was reached), the trial was scored, and the subject was provided with two forms of knowledge of results: (1) an "explosion of asterisks" if the trial was scored correct, the correct, the correct answer if the trial was scored incorrect; and (2) a display showing the cumulative RT for the present trial block, cumulative accuracy level, and present trial RT in msec (for correct trials).

After the first nine 30-trial blocks of trials, subjects were given 75 min of ability tests, a ten-minute break, and then returned to complete the second nine 30-trial blocks of task trials. In the second experimental session, an additional nine 30-trial blocks were administered, along with remaining ability tests. The second experimental session occurred one to two days after the first. Thus, a total of 27 blocks of task trials (810) was administered.

Results

Ability Factors. Based on the use of a series of factor analytic techniques (see Ackerman, 1988), four first order ability factors, and a second order General/Spatial ability factor were identified. The critical ability-performance results will be presented with respect to the (1) General/Spatial factor, the (2) Perceptual Speed factor, and the (3) Psychomotor/RT factor.

Performance Results. The performance data mirror results from earlier experiments, as well as predictions from the theory. Reaction times start out reasonably fast (Session 1 -- $\hat{\mu}$ = 1,252 msec, $\hat{\sigma}$ = 244 msec, accuracy $\hat{\mu}$ = 90.0%). Reaction times decline rapidly initially, and then show a slowing of improvements with further practice (Session 9 -- $\hat{\mu}$ = 731 msec, $\hat{\sigma}$ = 120 msec, accuracy $\hat{\mu}$ = 87.6%.). Clearly, the magnitude of inter-individual differences also declined with practice. Over the 810 trials of practice, $\hat{\sigma}$ dropped 51%.

Ability-Performance Correlations. The relevant ability-performance correlations over task practice are all presented in Figure 7. First of all, one should note that the General/Spatial ability-performance correlations start out at a moderate level, and decline with practice, as predicted by the theory. Second, though the data are noisy, there is a trend for the Perceptual Speed ability to follow the expected pattern of increasing - then decreasing correlations. Most important for this experiment, though, is the demonstration that the psychomotor "RT" ability showed increasing correlations with performance as the skill is acquired. Clearly, this pattern of results is consistent with predictions from the theory.

Although the sample is somewhat smaller for this experiment than for the previous ones, the Perceptual Speed data seem to show an interesting pattern. Recall that the subjects were given rather lengthy breaks between groups of three sessions (i.e., after Sessions 3 and 6). The saw-toothed pattern of ability-performance effects seems to be caused by the distribution of practice. Within each group of sessions (with the exception of Session 1), the Perceptual Speed-performance correlations start off high and decline with practice. There was no *a priori* prediction of this effect, and it certainly merits further study.

Discussion

The data presented from this experiment were substantially in agreement with the data from previous experiments, as well as in agreement with the theoretical predictions. The particularly salient feature of the data was the increasing correlations between the derived Psychomotor "RT" ability factor and task performance over practice. These data set the stage for a final investigation of the theoretical predictions, this time in the context of a more complex task.

Experiment 2

This experiment used a substantially different task than was investigated in the previous experiments. The Kanfer-Ackerman Air Traffic Controller (ATC) task (see Kanfer & Ackerman, 1989) is a rule-based, real-time computer-driven task that simulates some of the activities performed by air-traffic controllers. The major restriction of this instantiation of the task is that the spatial information processing demands are severely limited (no graphics are used). Acquisition of skilled performance requires that subjects develop proficiency with rapid sequences of keystrokes associated with task moves. While the task is novel, the components are generally consistent, thus allowing for the development of task proficiency through the three phases of skill acquisition described in the proposed theory. As such, the same theoretical predictions are made for ability-performance relations over task practice.

Method

Subjects. Sixty-five (37 male, 28 female) students at the University of Minnesota participated in this experiment. The subjects were recruited from an introductory psychology course, and received both course credit and $25 for participating in the experiment (the experiment reported here was part of a larger study)

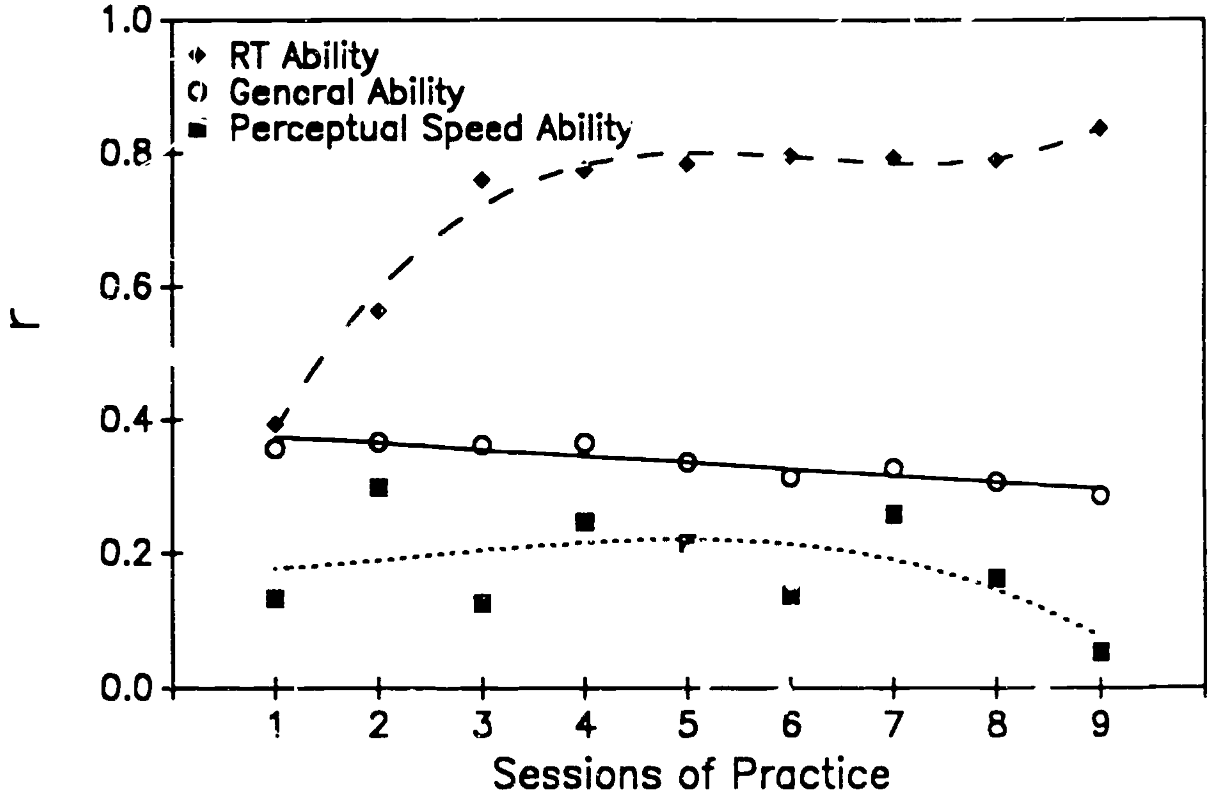

Figure 7. Ability-performance relations for the Discrimination RT task. Correlations between derived General/Spatial ability (General), Perceptual Speed ability, RT ability and task performance. Lines indicate linear regression of General ability loading over practice, and polynomial (cubic) regression of ability loadings for Perceptual Speed and RT. (From Ackerman, 1988. Copyright American Psychological Association.)

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Apparatus. Task instructions, simulation programing and presentation, and response collection were performed with IBM PC computers, with standard keyboards and IBM monochrome display monitors. A prototypical (albeit static) screen display of the ATC task is presented in Figure 8. As shown, the following task elements are displayed when subjects perform the task: (a) four runways, (b) 12 hold pattern positions, and (c) a queue stack with asterisks indicating planes requesting permission to enter the hold pattern. Two runways run North-South; two runways run East-West. One North-South and one East-West runway are short, the other two are long.

The hold pattern, located in the left section of Figure 8, is divided into three levels (analogous to three platters at different altitudes in the sky over the airport). Hold pattern position is indicated by number and letter in the Position (POS) column. Level 1 hold positions have the lowest altitude (i.e., closest to the ground) and Level 3 hold positions have the highest altitude. Four positions, corresponding to the points of the compass (i.e., N, S, E, W), are available in each level.

Planes are admitted to the hold pattern from the queue stack. The queue, located in the right side the screen, displays planes requesting permission to enter the hold pattern. Each plane request is represented by a period (.). Planes enter the queue at the rate of one every 7 sec. Plane requests remain in the queue until the subject places the plane in the hold pattern.

Plane information is displayed in the hold pattern. As shown in Figure 8, four types of planes enter the subject's hold pattern; 747's, 727's, DC10's, and Props. When a plane is placed in the hold pattern, flight number (FLT#), plane type (TYPE), and number of minutes of fuel remaining (FUEL) are displayed. Within each trial an approximately equal number of plane types are randomly drawn from the queue. Fuel remaining is determined when the plane is brought into the hold pattern, is randomly varied from four to six minutes. Once the planes enter the hold pattern, fuel remaining decreases in real time. When zero minutes of fuel remain, the plane crashes.

Subjects also receive information on airport weather conditions. Weather information is used (in accordance with the rule set) to determine what planes are allowed to land on which runways. Weather conditions are comprised of three elements; wind speed, wind direction, and ground condition. Wind speed and wind direction information is displayed on the "wind" line at the top right corner of the screen. Ground condition is displayed on the "runways" line. Updates to weather conditions are displayed throughout each task trial. Three levels of wind speed are presented, along with four levels of wind direction, and three levels of ground conditions. Changes in weather conditions (defined as a change in at least one of the three weather condition components) are varied randomly during a task trial. On average, these changes occur about twice a minute(i.e., 20 weather changes are displayed during each 10-minute task trial)

Feedback-Knowledge of Results. The first component of knowledge of results is the one-to-one mapping between keystrokes made by the subject, and operation of a cursor on the screen. As planes are selected, various parts of the display are highlighted. When a plane is moved from one hold position to another, or to a runway, the subject sees an analogous change to the display. Subjects also receive various types of continuously updated performance information throughout each trial; including cumulative performance landings, and errors.

```
FLT#    TYPE    FUEL    POS.
----    ----    ----    ----        Score    :  150
                        3 n         Landing Pts:  150  Penalty Pts:    0
                        3 s         Runways : DRY
 161     747      5     3 e         Wind     : 40 - 50 knots from SOUTH
                        3 w
 403     747      6     2 n         Flts in Queue: •••
 889     727      6     2 s                <F1> to accept
                        2 e
                        2 w
 631     727      6     1 n              Winds 40-50 knots
 144     prop     5     1 s              Winds from South
 903     DC10     6     1 e               Runways dry
 122     747   *  3     1 w

=========================== s   #1 <-

=========727=======         s   #2

||||||||||||||||||||||||||| e   #3        Can use short runways when:
                                        747 - Never         Prop - Always
||||||||||||||||||          e   #4      DC10 - Not Icy & not 40-50 knots
                                            727 - Dry or 0-20 knots
```

Figure 8. The Kanfer-Ackerman Air Traffic Controller Task. The figure is a literal static representation of the real-time task display. See text for a description of task elements. (From Ackerman, 1988. Copyright American Psychological Association.)

Task Rules. Six rules govern task performance. These rules describe the conditions required for successful manipulation of planes. When subjects perform actions that do not comply with a rule, the action command is ignored, an error message is presented on the screen indicating which rule is violated, and 10 points are deducted from the cumulative and penalty point scores. Rules 1 and 4 describe weather condition rules for landing planes onto runways. Rule 2 requires that plane landings must be initiated from one of the four hold pattern positions in Level 1. Rule 3 governs movement of planes within the hold pattern. Rule 5 requires that planes with 3 or less minutes of fuel left must be landed immediately. A warning asterisk is displayed next to the FUEL value when remaining fuel falls below four minutes (e.g., see FLT # 122 in Figure 8). If the plane is not landed prior to a FUEL value of 3, a penalty is incurred for each minute that subjects fail to land the plane. Rule 6 requires that only one plane occupy a runway at any time.

The task requirements. Three principal actions are performed by subjects: (1) accepting planes into the hold pattern, (2) moving planes in the three-level hold pattern, and (3) landing planes on appropriate runways. All three types of operations can be performed through the use of four keys on the computer keyboard. A one-to-one correspondence between keyboard and screen actions was maintained by linking each keyboard response to movement of a small cursor arrow on the screen (see the left side of Figure 8). Successful performance on this task requires knowledge of the rules governing plane movements and landings as well as knowledge about how to initiate plane movements using the computer keys.

Dependent Measures. Multiple performance measures were collected during ATC task trials, including number of planes landed, number of errors made, cumulative point total, and RT to changes in wind conditions. Given that the RT measure is a close analog to the speed of decision-response preparation measures used in other experiments, this measure is the focus of ability-performance relations described below.

Ability Tests. Twenty-two ability tests were administered to the subjects. The tests were selected to reveal six first order factors (Perceptual Speed, Movement Speed, Memory, Verbal, Reasoning, and Psychomotor [RT]), and a single second-order General ability factor.

Procedure

The experiment began with a set of instructions on the computer (that were simultaneously read aloud by the experimenter). Subjects then performed three, 10-minute task trials followed by a 5 minute break. Next, subjects alternated between task trials (in groups of three) and ability tests (for a total of three trial groups, or 9 trials in a day). Thus, the sequence for an experimental sessions was: task trials - break - ability testing - task trials - break - ability testing - task trials. This procedure was repeated for a second experiment session (separated by two days), for a total of 18 trials of the ATC task (180 minutes of total task practice). Remaining ability tests were administered during a third experimental session (as were other instantiations of the task - not reported here). Total time for the experiment was 10.5 hours over three sessions.

Results

Performance Results. The performance data were consistent with the experiments reported above. Reaction times in the complex task were much longer than for the simpler information processing tasks described to this point. Initial RT was slow (Session 1 -- $\hat{\mu}$ = 16.20 sec, $\hat{\sigma}$ = 9.20 sec). Again, RT's decline rapidly initially, and then show a slowing of improvements with further practice (Session 6 -- $\hat{\mu}$ = 5.11 sec, $\hat{\sigma}$ = 2.07 sec). Clearly, the magnitude of interindividual differences also declined with practice. Over the 6 sessions of practice, $\hat{\sigma}$ dropped 77%.

Ability Factors. Using procedures outlined in Ackerman (1988), the following ability factors were derived from the test battery: (1) Reasoning factor, the (2) Perceptual Speed factor, and the (3) Psychomotor/RT factor.

Ability-Performance Correlations. The relevant ability-performance correlations over task practice are all presented in Figure 9. The Reasoning ability shows performance correlations at an initially moderate level, and declines with practice, as predicted by the theory. The Perceptual Speed and Psychomotor (RT) ability-performance correlations do indeed follow the expected patterns of results; the Perceptual Speed ability showing increasing, then decreasing correlations, and the Psychomotor ability showing increasing correlations with performance as the skill is acquired. Clearly, although this was a much more complex task than those described above, this pattern of results is consistent with predictions from the theory.

Discussion

The ATC task and previous tasks (e.g., Ackerman, 1987; 1988) show that the theory predictions generally hold for RT, under a variety of different task scenarios. The results for choice reaction time, memory search, and rule-based skill tasks all point to the same general dynamic relations between abilities and performance during skill acquisition.

Adequacy of the theory. By and large the data have been congruent with the theoretical predictions. Manipulation of the degree of task consistency, complexity, and novelty have each illustrated dynamic ability-performance changes during skill acquisition phases.

Earlier claims of universal convergence or divergence of interindividual differences with practice must be qualified. The findings discussed in this report clearly indicate that both decreases and increases in inter-individual variability can be found, depending on task consistency. It should now also be clear that Fleishman's notion (1972; Fleishman & Quaintance, 1984) that post-practice individual differences are *specific only to the criterion task* are contradicted by the current data. The major determinants of individual differences before and after practice can now be delineated. Depending on the ability batteries used and the nature of the task demands, a greater amount of variance may be accounted for after practice than at the beginning of practice.

Simplex Revisited. In many respects the quasi-simplex pattern of intertrial correlations during skill acquisition (that Jones [1970] depends on for his explanation of individual differences) is a red herring. The first problem in using the simplex pattern as a springboard towards theory of individual differences was the underlying factorial

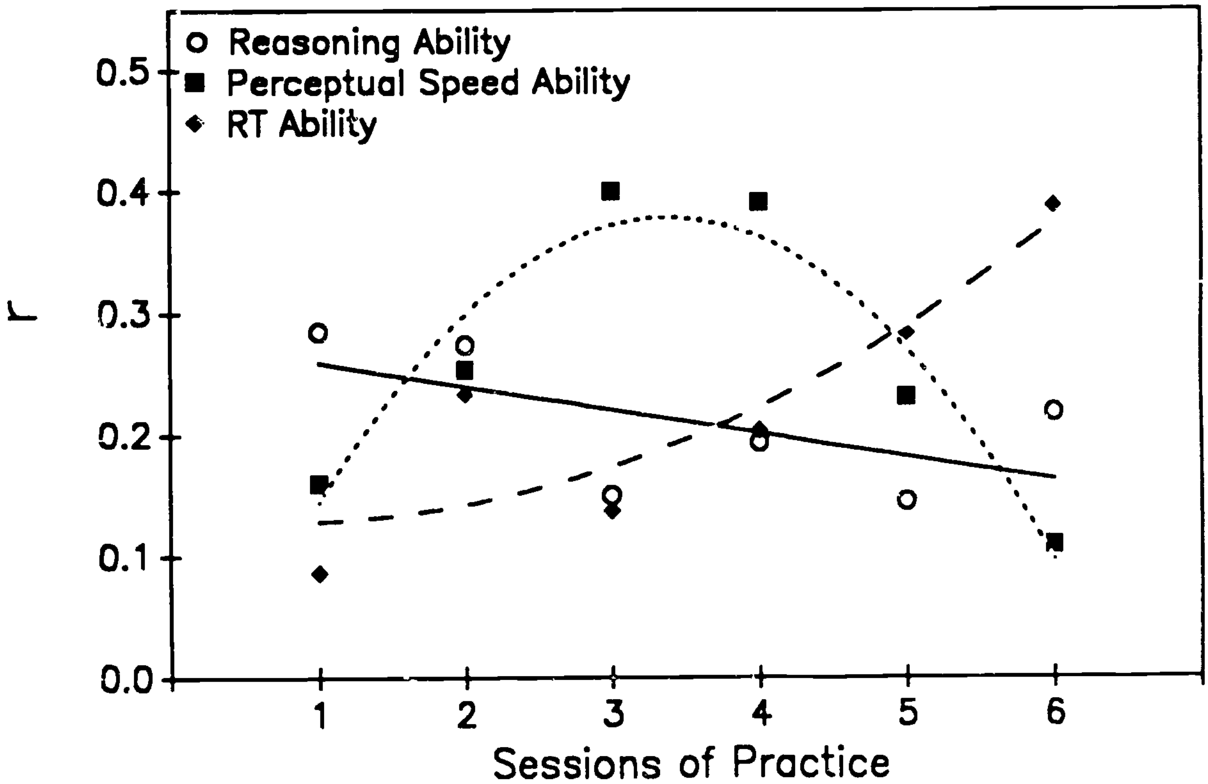

Figure 9. Ability-performance relations for ATC task. Correlations between derived Reasoning ability, Perceptual Speed ability, RT ability and task performance. Lines indicate linear regression of Reasoning ability loading over practice and polynomial (quadratic) regression of ability loadings for Perceptual Speed and RT. (From Ackerman, 1988. Copyright American Psychological Association.)

indeterminacy outlined by Corballis (1965). Furthermore, as Humphreys has noted (1985), the simplex pattern of correlations can be found in *any* individual differences data collected over several occasions. That is, the pattern is characteristic of repeated measures of intelligence or performance over time, just as it is characteristic of physiological measures of height and weight over occasions. The patterns merely represent a general law of flux in behavior over time. Finally, use of two measures taken from within-task intercorrelations (i.e., rate of attenuation and stability) failed to reflect the task-dependent changes indicated in the ability-performance data (Ackerman, 1988). Measures derived from within-task intercorrelations are simply too global to provide more than a rough index of the magnitude of change in *all* performance determinants over task practice.

Component Heterogeneity. Up to this point, tasks have been considered in terms of the dominant levels of complexity and consistency. When complex tasks have mixtures of components of differing levels of complexity and consistency, dynamic changes in ability-performance correlations will necessarily depend on these levels and parameters of component criticality. Thus, a finer degree of prediction is possible, based on an information processing decomposition of the tasks in question.

For example, take the construct of consistency. In the experiments reported above, consistency was manipulated "within-component." However, as Schneider & Fisk (1982b) have noted, for moderate degrees of inconsistent information processing. the nature of skill acquisition is dependent on whether inconsistency occurs between-components or within-components.

When inconsistency occurs between-components (i.e., some components are consistent, others are inconsistent), and, presumably when these task components are *separable*, the consistent components can be performed automatically after practice, while the inconsistent components remain controlled-processing intensive. (The Fisk & Schneider [1984] paradigm contrasted the consistency of attending [stimulus components] with the consistency of responding [response components].) Under such circumstances, skilled performance is limited by the controlled-processing intensive components.

The proposed theory predicts that initial performance on tasks with intermediate levels of consistency will be determined by the general ability (i.e., equivalent to other levels and types of consistency). After practice (normally associated with a transition to Phase 2), performance will still be determined to some degree by the general ability, because of the cognitive load associated with the inconsistent task components. As the general ability-performance association attenuates, perceptual speed will increase in influence. The extent of such influence will be determined by the number of consistent components present in the task. Similarly, the influence of the psychomotor ability will also be limited by the degree of controlled processing load caused by the inconsistent task components. As such, although the psychomotor ability may be related to asymptotic performance individual differences (for the consistent components), the *cognitive* determinants of performance are predicted to overshadow other abilities. That is, while psychomotor speed may increase in the *raw amount* of performance variance explained, the *relative* contribution will ultimately be small. To go beyond this description and for generation of point predictions of ability-performance correlations, it clearly will be necessary to translate these general principles to quantitative formulae.

PART IV. THEORETICAL EXTENSION: A DYNAMIC REPRESENTATION OF ABILITIES

The basic framework presented earlier implies a dynamic process underlying many perceptual speed and psychomotor abilities. With the possible exception of the most simple psychomotor tests (as well as tests that are highly practiced for most subjects or tests that require continuous involvement of controlled processing), tests of perceptual speed and psychomotor abilities involve some element of learning, and thus would be expected to show changes in underlying abilities, when practice is given to such tests. The expectation is that, given the same general learning framework described above, early practice on perceptual speed tests may be most associated with general and broad content abilities, whereas late practice on such tests (when the productions for test performance are effectively proceduralized) will be associated with psychomotor abilities. More bluntly, this means that performance on consistent perceptual speed tasks will be determined by individual differences in psychomotor abilities after practice. If this inference is correct, patterns of correlations between such abilities measures pre- and post-practice should show a temporal shift in the fashion depicted in Figure 10. Depending on the phase of skill acquisition on a criterion task, and the amount of practice on perceptual speed and psychomotor ability tasks, this framework predicts differing degrees of association between ability measures and test performance measures.

For the issue of skill specificity, the theory predicts that skill development will only be "specific" to the degree that perceptual speed measures (for intermediate stages of skill acquisition) and psychomotor ability measures (at the late stages of skill acquisition) are excluded from consideration (Ackerman, 1988), where "specificity" means a lack of prediction of individual differences in task performance. For the dynamic extension of the theory, one way to ameliorate the presence of skill specificity is to allow for practice on the perceptual speed and psychomotor measures. In this way, additional communality will be found with late performance on the criterion task. (This is a point similar to that made by Adams [1953] -- but it differs to the extent that specific classes of ability measures are predicted to increase in communality in this theoretical formulation.) As such, notions of skill specificity can be evaluated from both static (single testing occasion) and dynamic (pre- and post-practice on tasks) perspectives.

An Empirical Investigation

The experiment described below was designed to evaluate the dynamic characteristics of the ability-skill framework proposed above and to evaluate the issue of skill specificity. The basic outline for the experiment was to, first of all, collect performance data on a complex, but consistent, criterion task (the Kanfer-Ackerman Air Traffic Controller task). In addition, standard reference battery measures were used to assess the two components of the ability framework essential in early and intermediate phases of skill acquisition (i.e., general and perceptual speed abilities). Finally, two sets of perceptual speed ability tasks were selected to be used in a repeated-measure practice format. The first set included three tasks considered to be prototypical measures of perceptual speed ability, namely substitution, letter cancelling, and number checking. (For discussion of such measures as they relate to perceptual speed, see, e.g.. Ekstrom, French, & Harman, 1979; Thurstone, 1944.) The second set of perceptual speed (and to some degree, psychomotor) ability tasks was specifically

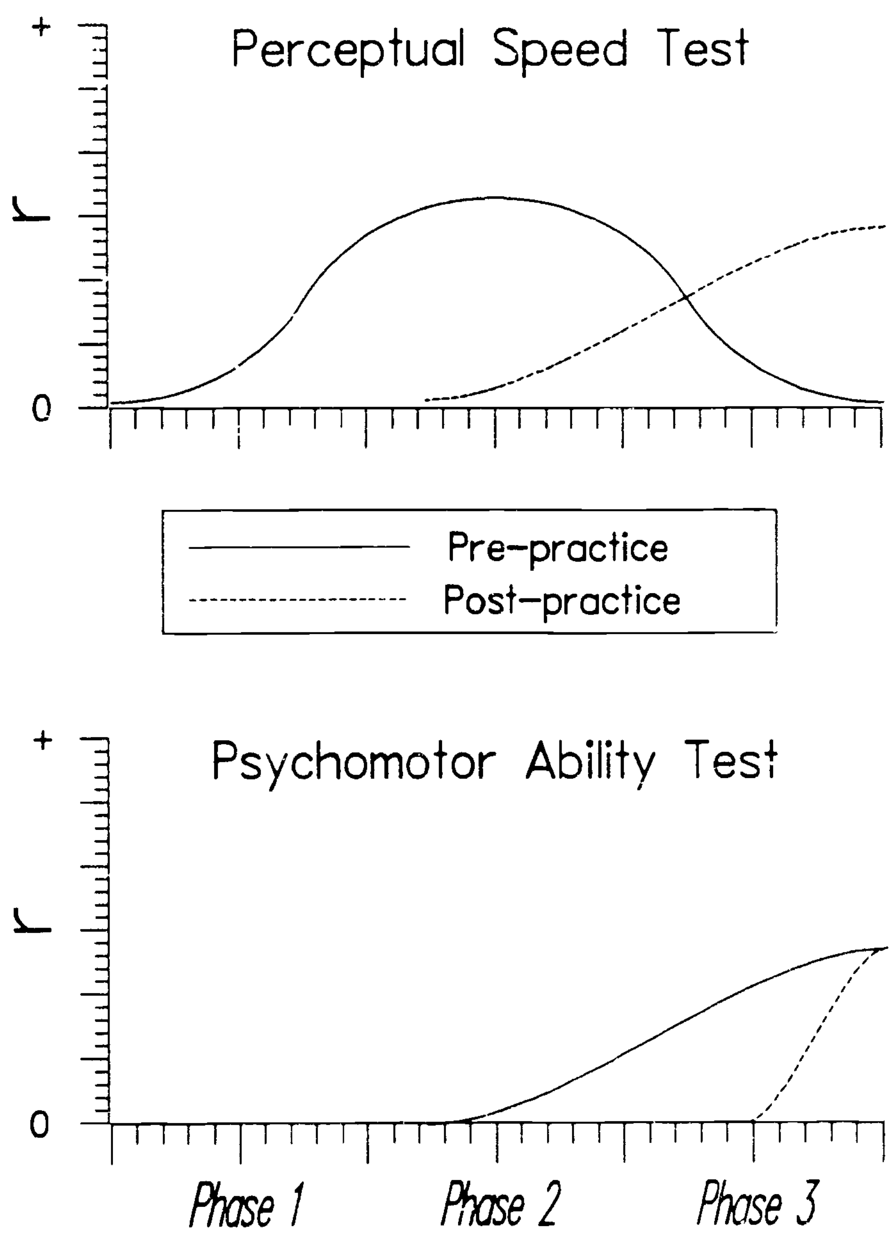

Figure 10. Hypothesized dynamic effects of practice on perceptual and psychomotor tests on the ability-performance relations.

chosen to be faceted in terms of the amount of information processing required for stimulus encoding and response selection. Four typical choice RT tasks were used, that varied in the number of stimulus and response alternatives, namely: nine-choice, four-choice, two-choice, and simple-RT. In this way, comparisons could be made across tasks that differed along a tractable dimension of information processing complexity. By examining the intercorrelations among reference test measures, practice task measures, and the criterion task performance, an evaluation of the theory-driven hypotheses could be undertaken.[1]

The purpose of this investigation, then, is three-fold: (a) to empirically demonstrate, via the use of an individual-differences approach, the limitations of skill specificity claims in the literature (especially as they pertain to individual differences); (b) to further validate a theory of the cognitive ability determinants of procedural learning; and (c) to provide a pre- and post-practice sampling of perceptual speed measures in comparison to individual differences in the acquisition of a complex procedural skill.

Experiment 3

Method

Subjects. One hundred and three undergraduate students at the University of Minnesota participated in this experiment. The subjects were recruited from an introductory psychology course, and received course credit for the first five hours of participation, and $27 for the remaining five hours of the experiment. However, because 11 subjects participated only for credit (i.e., did not return for second and/or third sessions), their incomplete data were excluded from analysis. In addition, through computer failure (3 subjects) or a failure to follow experimental instructions (5 subjects), data from a total of 8 other subjects were similarly incomplete, and were thus discarded prior to analysis. The results reported below were based on data for the 86 subjects with complete data.

Apparatus. For the criterion Air Traffic Controller task, the choice RT tasks, and the Simple RT task, instructions, simulation programing and presentation, and response collection were performed with IBM PC computers, with standard keyboards and IBM monochrome display monitors. For paper and pencil tasks, instructions (and timed start-stop directions) were presented over a public address system, using prerecorded tapes. Subjects were tested in groups of up to 14 at a time, in individual carrels (for the computer-based tasks) and at separate tables (for the paper & pencil tests).

Ability Testing -- Reference Tests. In order to confirm the theoretical predictions for ability-performance relations, as well as provide a reference of the ability demands

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[1] In a broad sense, this investigation is a theoretically motivated extension of the experiment designed by Adams (1953). However, many differences between the two empirical investigations exist. Most notable are the higher level of complexity and amount of practice for the current criterion task, the more extensive amounts of practice for the predictor measures, and the use of statistical tools for evaluating the associations between the various measures that were not available in the 1950s.

of the criterion task across practice sessions, seven reference tests (administered only once) were administered to the subjects. Four broad reasoning tests were selected a priori as markers for a general cognitive ability (Raven Progressive Matrices, Letter Sets, Figure Classification, and Analogies). Three tests were selected a priori as markers for perceptual speed ability (Perceptual Speed, Clerical Speed & Accuracy, and Number Sorting).

Dynamic Ability Assessment -- Practice Tasks. Three tasks identified in the literature as tapping aspects of perceptual speed ability were selected for extensive practice. These tasks included Cancelling A's, Number Comparison, and Letter/Number Substitution. In addition, four tasks that were identified on a continuum from perceptual speed to psychomotor abilities were also selected for extensive practice. These were Nine-Choice RT, Four-Choice RT, Two-Choice RT, and Simple RT. (Typically, simple RT tasks are considered predominantly psychomotor -- e.g., see Ackerman, 1988; Fleishman, 1954). With the exception of the Number Comparison task, each of these 7 tasks can be considered having an underlying consistent mapping of stimuli and responses (see Shiffrin & Schneider, 1977, for a discussion of consistent mapping). For the Number Comparison task, only a higher-order consistency exists between finding a "match" and writing a check-mark. Given that no numbers were repeated in this task, it can be considered to have a varied mapping of stimuli (the individual numbers) and responses.

Criterion Learning Task (Air Traffic Controller). The Air Traffic Controller Task described above was used in its standard configuration.

Procedure

The first session of the experiment began with a set of instructions on the computer for the Air Traffic Controller (ATC) task. Subjects then performed three, 10-minute task trials. Next, subjects alternated between ability tests, on the computer or using a paper and pencil format, and criterion task trials (in groups of three) for a total of three trial groups (9 trials) in a day, with interspersed breaks. The sequence for an experimental session was: task trials - ability testing - break - task trials - ability testing - break - task trials. This procedure was repeated for the second session (separated by two days), and partially repeated for the third experiment session (again, separated by two days). In the third session, though, only two 3-trial ATC sets were administered, for a total of 24 trials of the ATC task (240 minutes of total task practice). Each of the first two sessions lasted 3½ hours, and the third session lasted 3 hours, for a total of 10 hours.

In the first session, subjects were tested on Clerical Speed & Accuracy, Perceptual Speed, Number Sorting, Letter Sets, baseline measures of the Choice and Simple RT tasks, and practice on the Letter/Number Substitution task. In the second session, subjects were tested on the Raven Progressive Matrices, and received practice on the Number Comparison, Nine-Choice RT and Four-Choice RT tasks. In the third session, subjects were tested on Figure Classification, Analogies, and received practice on Two-Choice RT, Simple RT, and Cancelling A's tasks.

Results

Criterion Task -- Means, sd's. For the ATC criterion task, performance[1] shows a unequivocal improvement with task practice, and the expected reduction in between-subject standard deviations ($\hat{\mu}_{initial}$ = 22.19 sec., $\hat{\sigma}_{initial}$ = 8.82 sec.; $\hat{\mu}_{final}$ = 9.87 sec., $\hat{\sigma}_{final}$ = 1.35 sec.). These effects are shown graphically, across the entire set of practice sessions, in Figure 11. Reductions of both mean and standard deviations are significant (for means, $F(7,595) = 158.64$, $p \leq .01$; for $\hat{\sigma}$'s, $\chi(85)$, for $\alpha = .01$ critical value = 1.43, actual value = 6.53). The learning curve reflects the typical negatively accelerating reduction in RT with practice on consistent tasks in accordance with the Power Law of Practice (e.g., see Newell & Rosenbloom, 1981).

Practice Tasks

Descriptive statistics for the practice tasks are presented in Table 1. For each task, both initial (first task) and final (last task) means and standard deviations are shown, along with differences between the two and intercorrelations. The pattern of results for these tasks indicate the diversity in characteristics of so-called perceptual speed tasks (although the Simple RT, and perhaps the Two-choice RT are arguably psychomotor ability tasks). Degree of learning for these tasks is indexed by the changes between initial and final mean RT and the changes in $\hat{\sigma}$. With the exception of the Letter/Number Substitution and Simple RT tasks, all others indicated significant reductions in mean RT with practice ($\hat{\mu}_i - \hat{\mu}_f$). Four tasks, Nine-Choice RT, Four-Choice RT, Two-Choice RT, and Cancelling A's, showed significant reductions in between-subject $\hat{\sigma}$ ($\hat{\sigma}_i - \hat{\sigma}_f$). Such results are consistent with the expectations of reductions in variability that occur with the development of automaticity (Ackerman, 1987). However, the other three tasks, Number Comparison, Letter/Number Substitution and Simple RT showed stable (or in the case of Simple RT, increasing) between-subject standard deviations. While this was expected for the Number Comparison task (given its general lack of consistent mapping), any explanation of the other results would be ad hoc. The significant increase in standard deviation in the Simple RT could possibly be caused by the temporal uncertainty involved in the task (see, for example, the discussion by Stroud, 1955). As such, this would comprise one facet of the task that is not consistently mapped. For the Letter/Number substitution task, there is no obvious explanation for the lack of decrease in either RT or standard deviation.

For space considerations, the seven inter-occasion intercorrelation matrices are not presented here. However, as with the criterion task, and indeed all multi-occasion data, these intercorrelations show the simplex-like ordering, with the largest values found in the adjacent correlations, and declining correlations with increasing occasion differences. In general, the smallest intercorrelations were found between the initial and final tasks of each type. Nonetheless, a large range of stabilities was evident in these different tasks. The highest stability was obtained with the Cancelling A's task (a highly consistent, simple task), however, no clear pattern emerged across the tasks.

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[1] For the criterion task performance measure (planes landed), and for all other practice task measures, if raw scores used attainment measures (e.g., the number of items completed within a fixed time period), the scores were converted to RT measures (a reciprocal transformation, with a constant determined by the time limit). Thus all practice measures are on a the same ratio scale of measurement -- such measures indicate the amount of time taken to correctly complete one item.

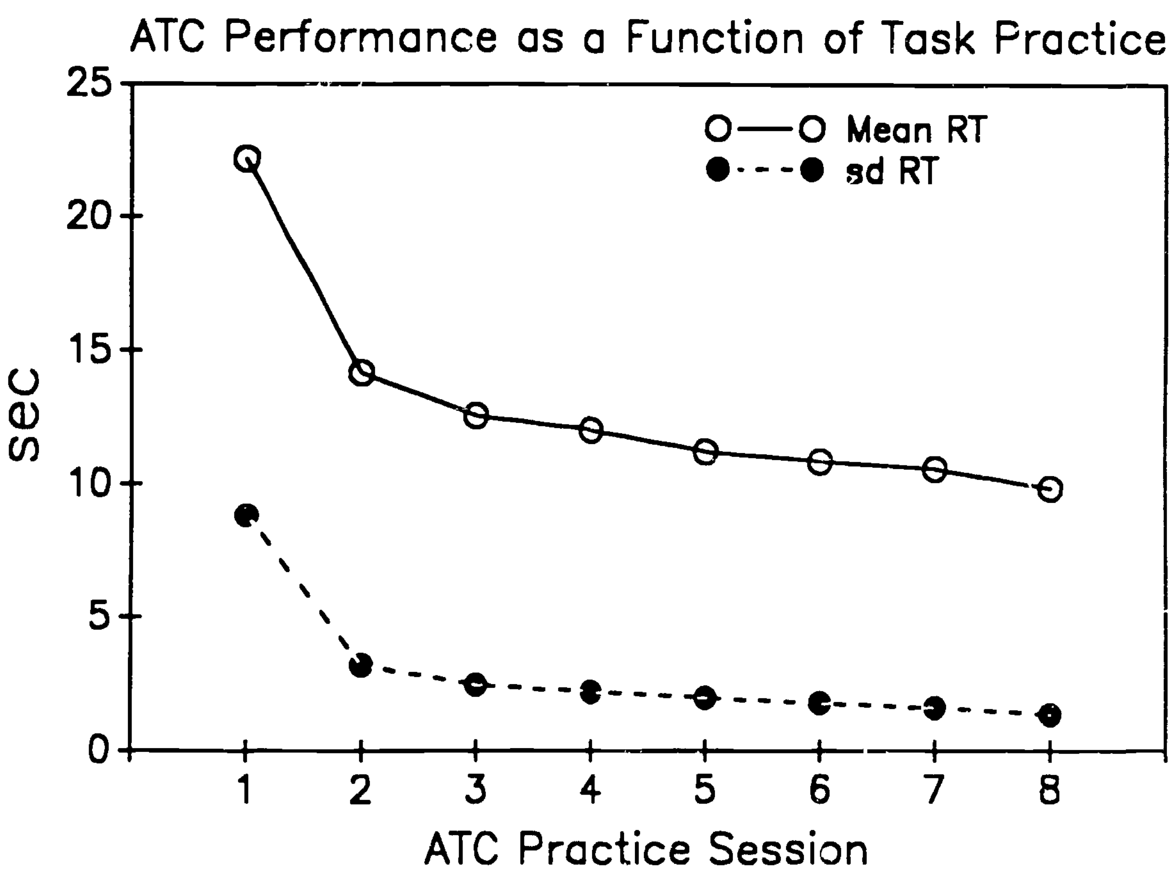

Figure 11. Mean RT (across subjects and practice sessions) and between-subject standard deviation (sd) measures as a function of practice on the ATC task. Each session of practice contained three 10-minute trials.

Table 1. Descriptive statistics for practice tasks[1]

Task	M_i	sd_i	M_f	sd_f	M_i-M_f	sd_i-sd_f	$r_{i,f}$
1. Nine-Choice RT	909.	158.	653.	101.	256.**	57.**	.57**
2. Four-Choice RT	580.	90.	558.	85.	22.*	5.	.41**
3. Two-Choice RT	403.	75.	376.	46.	27.**	29.**	.37**
4. Simple RT	265.	40.	265.	50.	0.	-10.**	.47**
5. Letter/Number Sub.	1,382.	232.	1,406.	258.	- 24.	-26.	.43**
6. Number Comparison	3,141.	618.	2,752.	670.	389.**	-52.	.39**
7. Cancelling A's	2,392.	666.	2,123.	531.	269.**	135.**	.87**

[1] Numbers are in msec, except for correlations in last column.
$_i$ = initial; $_f$ = final, post-practice; * $p \leq .05$; ** $p \leq .01$.

Ability-Performance Correlations -- Reference Battery. To establish that the patterns of ability determinants on the criterion task are in agreement with the theoretical predictions, the seven reference tests used as markers for General Ability (g) and for Perceptual Speed ability were subjected to a factor analysis. For this analysis, two factors were allowed (in accordance with the a priori selection of tests to represent two factors), and an orthogonal varimax rotation was used. Test intercorrelations and the factor solution are presented in Table 2. As shown, the tests chosen as markers substantially loaded only on the factors expected. From these results and from the a priori selection of measures, Factor I was labeled g and Factor II was labeled Perceptual Speed. The last step in determining ability-performance correlations was the use of the Dwyer extension procedure (Dwyer, 1937) for determining the factor loadings (i.e., correlations with the abilities in this orthogonal factor space) of the individual task performance measures. For a detailed discussion of this procedure, see Humphreys (1960; also, see Ackerman, 1986a, 1987).

This series of calculations provides correlations between the predetermined reference factors and the performance measures on the criterion task. These data are presented in F[illegible] 12. Such results map closely to those expected from the theory and from pre[illegible] results with this task (e.g., Kanfer & Ackerman, 1989). As predicted, init[illegible] performance individual differences were most associated with g, with declining correlations over task practice. Conversely, correlations between Perceptual Speed and performance were modest in the first session of performance, then increased as an intermediate level of criterion skill was acquired, leveling off at the end of the allowed practice period. Sufficient practice (240 min. of total time-on-task) was given to allow for some modest amount of automaticity in task components (Ackerman, 1988). The slight (albeit non-significant) decline in Perceptual Speed-performance correlations for the last three sessions is consistent with this inference, as are the mean and variability measures for performance.

Ability-Performance Correlations -- Pre-/Post-Practice. The critical results for evaluating the theory and the skill-specificity hypothesis are the pre-practice and post-practice patterns of ability-performance relations. For the sake of brevity, only the first and last practice tasks are used for this set of analyses. Since these provide the most extreme amounts of practice, such data make for the clearest evaluation of the hypotheses. (In fact, the intermediate practice results demonstrate intermediate patterns between the initial-final data.)

Figure 13 shows the correlations between the 8 ATC practice session performance measures with initial (pre-practice) task performance and final (post-practice) task performance for the Nine-Choice RT, Four-Choice RT, Two-Choice RT, and the Simple RT tasks. The patterns of results for the choice RT tasks are consistent with theoretical predictions, made in Figure 10.[1] Pre-practice task performance measures

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[1] The sampling distributions for the differences between two sets of curves of correlations are not readily determined. Statistical tests of the differences between individual pairs of correlations seriously underestimate the aggregate patterns, while tests of average correlation differences would obscure any apparent interaction effects. Test of the regression estimates (e.g., trend analysis) for such curves do not provide a ready solution either, since the individual data points are correlations, rather than individual observations (for examples, see Ackerman, 1988). Nonetheless, the differences between these curves pass both the less precise "interocular impact test," as

Table 2. Reference battery intercorrelations and factor solution.

Intercorrelations[1]

Test		1	2	3	4	5	6	7
1.	Clerical Speed & Accuracy							
2.	Perceptual Speed	.41						
3.	Number Sort	.40	.31					
4.	Letter Sets	.11	.12	.20				
5.	Raven Progressive Matrices	.22	.33	.30	.46			
6.	Figure Classification	.26	.25	.26	.42	.44		
7.	Analogies	.10	.19	.26	.30	.47	.14	

Factor Solution[2]

Test		Factor I	Factor II
1.	Clerical Speed & Accuracy	.050	**.774**
2.	Perceptual Speed	.216	**.519**
3.	Number Sort	.273	**.492**
4.	Letter Sets	**.620**	.078
5.	Raven Progressive Matrices	**.777**	.250
6.	Figure Classification	**.472**	.286
7.	Analogies	**.484**	.133

[1] Correlations larger than r = .183 are significant at $p \leq .05$, one-tailed.

[2] Factor loadings greater than .300 are in boldface.

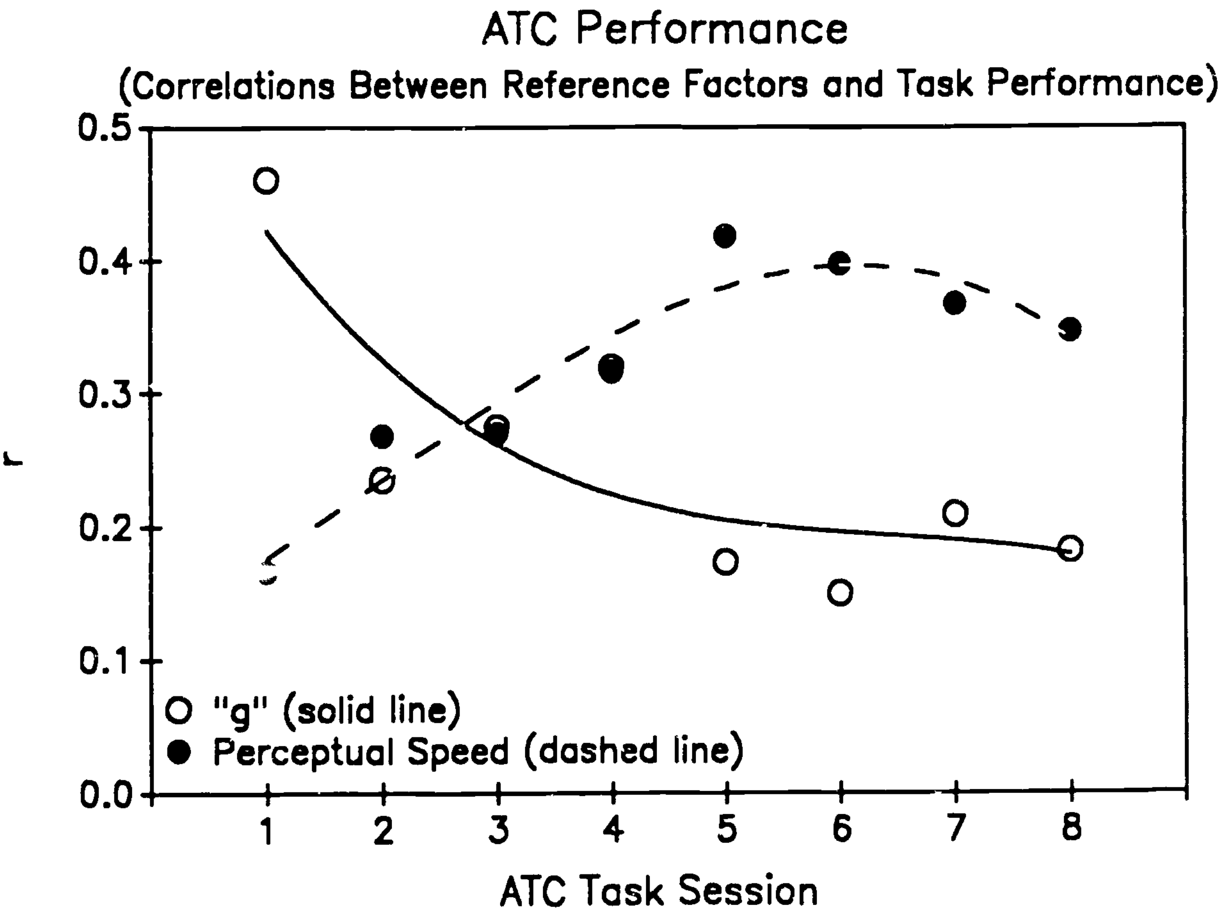

Figure 12. Ability-performance relations for the ATC task. Correlations between task performance and derived General and Perceptual Speed abilities. Solid line indicates regression of General ability (cubic polynomial) loadings over practice. Smooth line indicates regression of Perceptual Speed (cubic polynomial) loadings over practice.

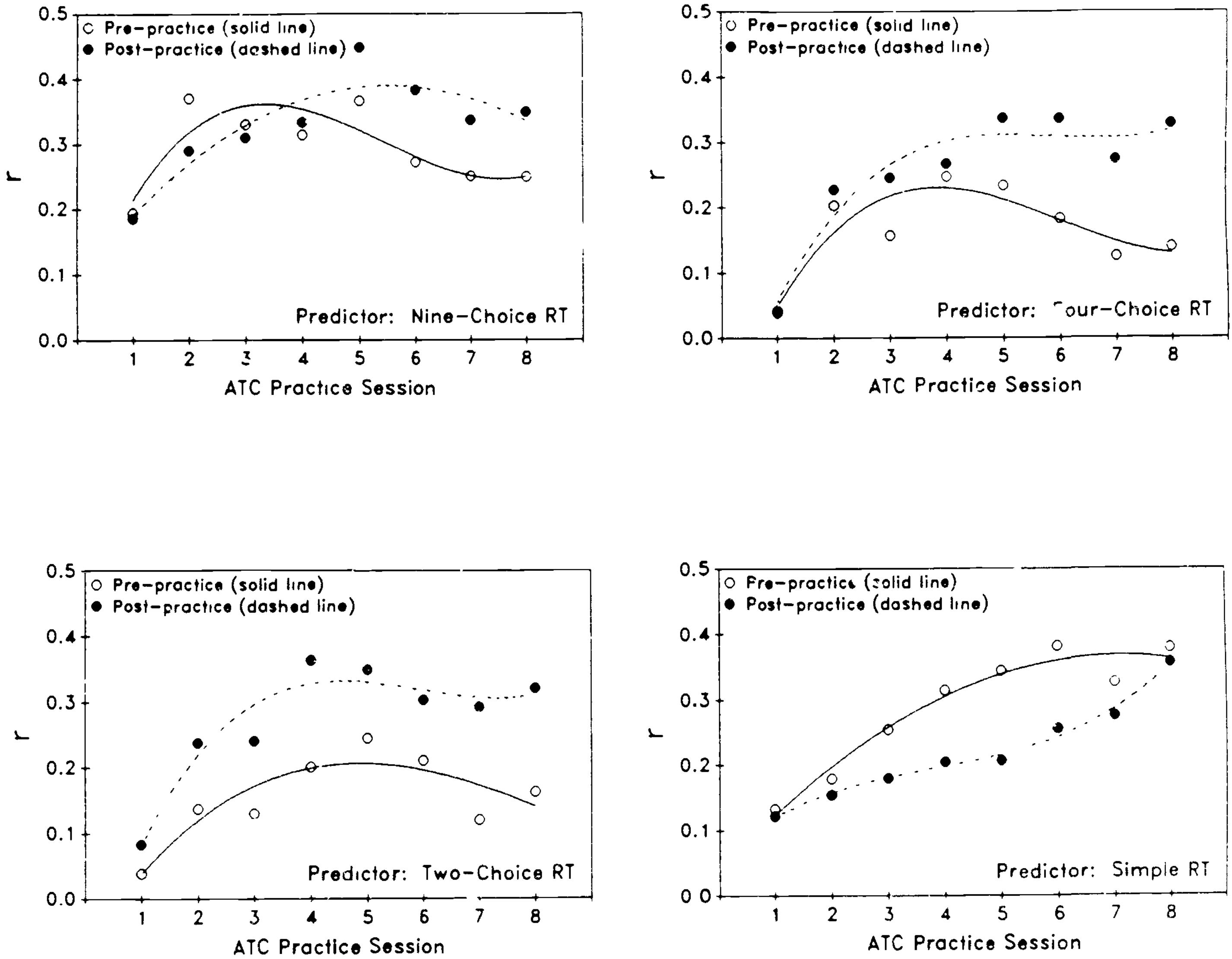

Figure 13. Ability-performance relations for the ATC task as a function of practice on Nine-Choice RT, Four-Choice RT, Two-Choice RT and Simple RT tasks and practice on the ATC task. Solid lines indicate cubic polynomial regression of first occasion task performance (pre-practice) on ATC task performance. Dashed lines indicate cubic polynomial regression of last occasion task performance (post-practice) on ATC task performance.

for the Nine-Choice, Four-Choice, and Two-Choice RT tasks indicate low correlations with early criterion task performance, with increasing, then decreasing correlations as criterion task practice continued. Post-practice task performance, though, showed larger correlations with the criterion task as criterion task practice continued. For these choice-RT tasks, post-practice task performance correlations have larger correlations with final criterion task performance (that is, higher than pre-practice task performance-criterion task correlations).

The Simple RT task shows a pattern of results consistent with its classification as a psychomotor ability (see the predictions in Figure 10). That is, even in the pre-practice version of the task, there is no apparent decline in criterion task performance correlations. Although additional criterion task practice may have shown a crossover of correlations, the trend in post-practice task - criterion task correlations clearly indicates that the post-practice version of the Simple RT task would be most associated with highly practiced levels of the criterion task.

For the other three practice tasks, the pre-practice and post-practice task - criterion task performance correlations are presented in Figure 14. These curves illustrate both similarities and striking differences from the choice RT measures described above. First, the higher initial correlations obtained in the pre-practice Letter/Number Substitution task demonstrates the strong memory component associated with the task. In fact, this task behaves very much like the measures of **g** (see Figure 12), with the largest correlations at the initial sessions of criterion task performance. However, after practice on the Letter/Number Substitution task, the correlations with the criterion task follow the pattern that would be expected of a perceptual speed test.

The Number Comparison task, with strong demands on controlled processing, shows a pattern of criterion task correlations that would be expected of a perceptual-speed ability measure, similar to the increasing, then decreasing pattern found in the choice-RT tasks (and the reference perceptual-speed measures). However, increasing task practice results in less communality with the criterion task performance.

The highly simple and consistent Cancelling A's task behaves mostly like a psychomotor test (e.g., the Simple-RT task), both in pre- and post-practice versions. That is, there is an overall increase in communality between task performance and criterion task performance as practice increases on the criterion task. However, additional practice on the Cancelling A's task only results in a reduction in communality between task performance and criterion task performance, an indication that developed skills in both tasks have less in common than the other tasks examined above.

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well as less elegant non-parametric tests. (For example, a low-power sign test would allow rejection of a null hypothesis at the $p = .05$ level, that the two curves are the same, when 7 or all 8 of the pairs differ in the same direction.) For the data presented in Figures 7 and 8, such significant sign-test results would be detected in all cases except for the interactions apparent in the Nine-Choice RT and the Letter/Number Substitution tasks. More sensitive, parametric tests, would yield identical conclusions.

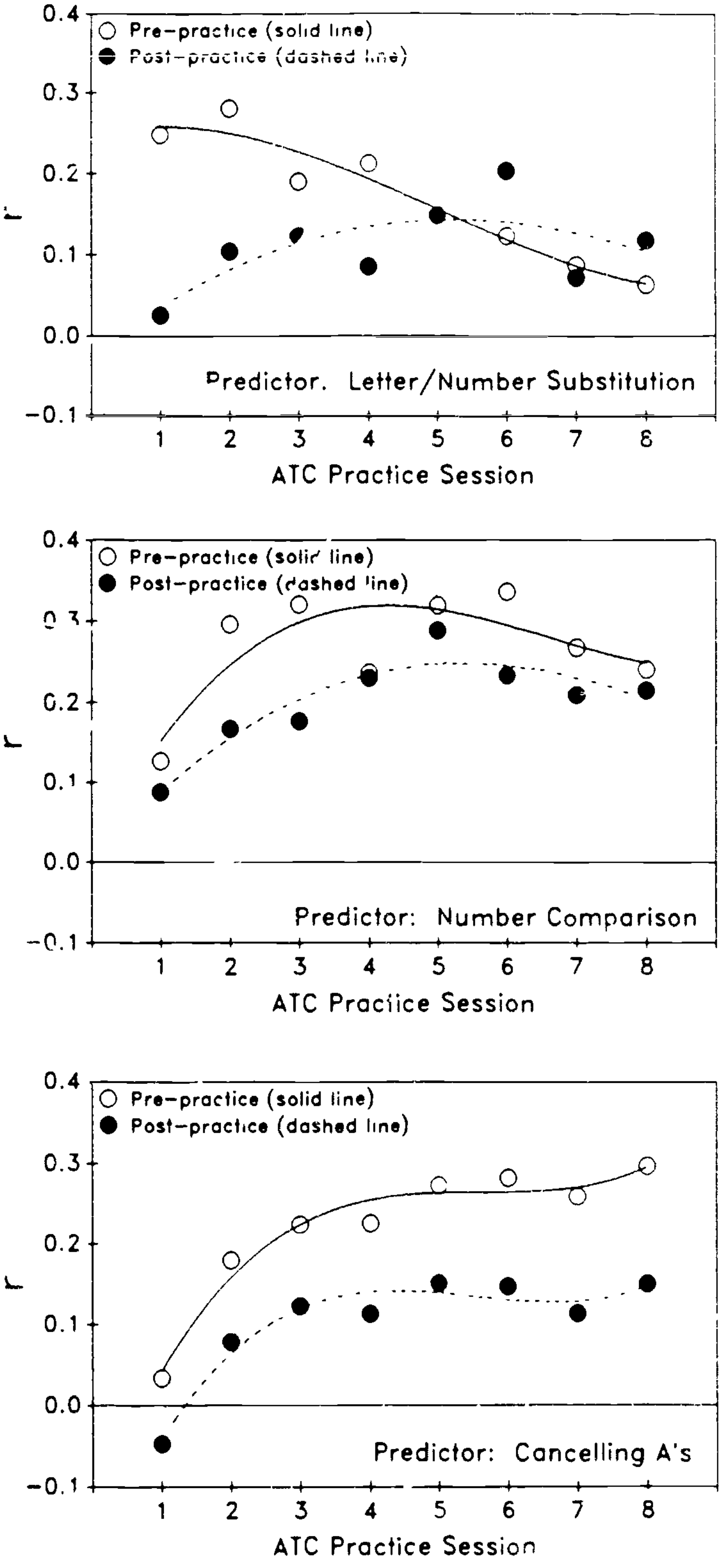

Figure 14. Ability-performance relations for the ATC task as a function of practice on Letter/Number Substitution, Number Comparison, and Cancelling A's tasks and practice on the ATC task. Solid lines indicate cubic polynomial regression of first occasion task performance (pre-practice) on ATC task performance. Dashed lines indicate cubic polynomial regression of last occasion task performance (post-practice) on ATC task performance.

Overall, five of the practice tasks show decisive <u>increases</u> in association with criterion task performance (Nine-Choice RT, Four-Choice RT, Two-Choice RT, Simple RT, & Cancelling A's), a clear disconfirmation of skill specificity for the ATC criterion task. In addition, three of these tasks (namely, the Nine-Choice RT, Four-Choice RT, and the Two-Choice RT) show additional increases in association with the late criterion task performance, <u>after</u> substantial practice was given on those practice tasks.

<u>Cross-Correlations Between Practice Tasks</u>. Another way to index the degree of skill specificity, although on a much shorter time/practice scale, is to examine intercorrelations among the seven practice tasks. That is, the same pre-/post-practice analysis can be used, designating the practice tasks as the to-be-predicted criteria. When tasks show increases in correlation (or communality) with post-practice performance of other tasks, additional evidence against the skill specificity hypothesis is acquired. Furthermore, these intercorrelations allow for assessment of the theoretical inference about the dynamic properties of the perceptual speed measures (namely, that practiced consistent perceptual speed tasks tap individual differences more closely associated with psychomotor abilities than perceptual speed abilities).

For this analysis, four sets of correlations are of interest: namely, the synchronous cross-correlations for initial and final tasks (i.e., the correlations between each of the tasks, at the same stage of practice) and the cross-lagged correlations between the tasks. These correlations are presented in Table 3 and Table 4, respectively. Although only two pairs of individual synchronous correlations significantly differ from one another (the Number Comparison - Four-Choice RT pair (z = 2.00, $p \leq .05$) and the Number Comparison - Letter/Number Substitution pair (z = 2.31, $p \leq .05$), a striking trend emerges from examination of the sets of correlations for the Choice/Simple RT tasks in contrast to the Letter/Number Substitution, Number Comparison, and Cancelling As tasks. This trend is that the Choice/Simple RT measures show higher post-practice intercorrelations at the end of practice than they do at the beginning of practice. Although this is apparent by contrasting the pre- and post-practice synchronous correlations in Table 3, more precise estimates of communality were computed by using a multiple correlation procedure. For the Choice/Simple RT tasks, average communality among these measures was R^2 = .30 before practice, and R^2 = .42 after practice ($t(6)$ = 5.68, $p \leq .05$). No such trend was found for the other three tasks (initial average R^2 = .17, final average R^2 = .15, n.s.). Because the power of this type of test is modest, it can be said that the Choice/Simple RT tasks tend to share more variance with practice, while the null hypothesis of no change in communality cannot be rejected for the three paper and pencil task measures.

<u>Cross-Lagged Correlations</u>

The cross-lagged correlations shown in Table 4 address the consequences of practice upon the nature of perceptual speed task performance. In particular, the significant differences in cross-lagged coefficients found for the Nine Choice RT/Simple RT and the Four Choice RT/Simple RT pairings (and the non-significant, but similar trend for the Two Choice/Simple RT pair) support the basic premises of the theory. That is, these cross-lagged correlations show that <u>late</u> performance on the Nine-Choice RT, the Four-Choice RT (and to a non-significant degree, the Two-Choice RT) has <u>more</u> to do with <u>early</u> performance on the Simple RT task than the converse (i.e., early performance on these three tasks has little to do with late performance on the Simple RT task). Again, these results support the theoretical predictions shown in Figure 10

Table 3. Synchronous correlations among practice tasks and correlations between practice tasks and ability factors.[1]

<u>Synchronous Correlations</u> (Pre-Pre Below Diagonal/Post-Post Above Diagonal)

Practice Tasks	1	2	3	4	5	6	7
1. Nine-Choice RT	--	.65	.45	.26	.23	.11	.23
2. Four-Choice RT	.59	--	.56	.43	.11	**.00***	.23
3. Two-Choice RT	.25	.42	--	.48	-.01	.05	.08
4. Simple RT	.30	.32	.37	--	-.11	.00	-.05
5. Letter/Number Sub.	.21	.21	.13	-.02	--	**.03***	.24
6. Number Comparison	.34	**.30***	.16	.12	**.37***	--	.41
7. Cancelling A's	.28	.21	.08	.10	.20	.38	--

Correlations between Practice Tasks and Ability Factors

	1	2	3	4	5	6	7
<u>Pre-Practice</u>							
g	.03	.18	.16	.09	.09	.03	.01
Perceptual Speed	.18	.06	.22	.22	.45	.66	.56
<u>Post-Practice</u>							
g	.09	.02	.22	.24	.10	.06	.09
Perceptual Speed	.26	.25	.16	.01	.38	.70	.58

[1] Pairs in boldface are significantly different from one another; * $p \leq .05$; ** $p \leq .01$, two-tailed. Individual correlations larger than $r = .183$ are significant at $p \leq .05$, one-tailed. i = initial, f = final.

Table 4. Cross-lagged correlations among practice tasks.[1]

Cross-Lagged Pairs Left	Right	r left$_i$,right$_f$	r left$_f$,right$_i$
1. Nine-Choice RT	Four-Choice RT	.44	.37
2. Nine-Choice RT	Two-Choice RT	.26	.25
3. Nine-Choice RT	Simple-RT	**-.03****	**.46****
4. Nine-Choice RT	Letter/Number Sub.	.08	.20
5. Nine-Choice RT	Number Comparison	.13	.30
6. Nine-Choice RT	Cancelling A's	.17	.32
7. Four-Choice RT	Two-Choice RT	.32	.18
8. Four-Choice RT	Simple-RT	**.01****	**.46****
9. Four-Choice RT	Letter/Number Sub.	.18	.04
10. Four-Choice RT	Number Comparison	.17	.00
11. Four-Choice RT	Cancelling A's	.18	.23
12. Two-Choice RT	Simple-RT	.24	.40
13. Two-Choice RT	Letter/Number Sub.	.11	.06
14. Two-Choice RT	Number Comparison	.12	.16
15. Two-Choice RT	Cancelling A's	.13	.10
16. Simple-Choice RT	Letter/Number Sub.	**.07***	**-.27***
17. Simple-Choice RT	Number Comparison	.10	06
18. Simple-Choice RT	Cancelling A's	.05	.01
19. Letter/Number Sub.	Number Comparison	.07	.32
20. Letter/Number Sub.	Cancelling A's	.22	.13

[1] Pairs in boldface are significantly different from one another; * $p \leq .05$; ** $p \leq .01$, two-tailed. Individual correlations larger than $r = .183$ are significant at $p \leq .05$, one-tailed. i = initial, f = final

-- that with practice, consistent perceptual speed measures more closely resemble psychomotor abilities after practice (on the perceptual speed measures). A graphic depiction of the full cross-lagged correlational information (for the Nine-Choice RT and Simple RT tasks) is presented in Figure 15. Trends found elsewhere in the table are generally supportive of the thesis, however the large sampling error for the difference between independent correlations precludes definitive statements from being made about the remaining pairs of correlations.

Discussion

The first element of the results presented here is that reference factors of g and Perceptual Speed abilities are consistent with the Ackerman (1988) ability-performance theory expectations for a consistent, procedural learning task. With those prerequisite results as a foundation, the practice tasks could be examined to evaluate the extension of the theory to encompass dynamic ability-skill relations, and to evaluate hypotheses about the nature of skill specificity from an individual-differences perspective. The obtained results provide support for these theoretical extensions. Specifically, analyses of patterns of changing correlations, changes in means and standard deviations with task practice, the synchronous and the cross-lagged correlations supported the theory extensions. The Nine-Choice, Four-Choice, and Two-Choice RT tasks tend to have more in common with early practice on the simple RT task (where the information processing demands are reduced). Not only did these post-practice perceptual speed task measures appear to jointly reflect psychomotor abilities, they concomitantly showed increases in communality with each other, and with practiced levels of performance on the more complex ATC task. As such, skills in these diverse tasks were similar to the degree that individual differences in performance on some tasks increased in communality with individual differences in performance on the other tasks. This demonstration is made more powerful by the observation that significant decreases in interindividual variability were found over practice for the ATC task and for the Nine-Choice RT and the Two-Choice RT tasks. If these correlations were corrected for this restriction of range, the magnitude of observed differences between pre- and post-practice correlations would actually become exacerbated -- further support for the theoretical predictions.

The fact that the other perceptual speed practice tasks do not uniformly show increasing communality with each other does not negate the conclusions about skill specificity for the ATC task. Rather, this aspect of the data only reinforces the notion that without specific a priori information processing models of test performance, it is impossible to univocally determine the nature of the underlying ability components of test performance, both initially, and subsequent to repeated test practice occasions. In addition, such results testify against an argument that correlations between tasks must increase with task practice -- that is, an argument that the other findings were caused by some unknown psychometric artifacts.

The findings obtained here inform issues of skill specificity from an experimental perspective in several ways. First, the use of the integrated individual differences - information processing approach precludes many problems of measurement and inference that occur throughout the training and transfer research literature (such as those described by Singley & Anderson, 1989). Although the resulting data do not directly address the "transferability" of skill from one task to another, the results indicate that individual capabilities for procedural skill performance are substantially related across similar types of procedures. Such data support the concept that abilities

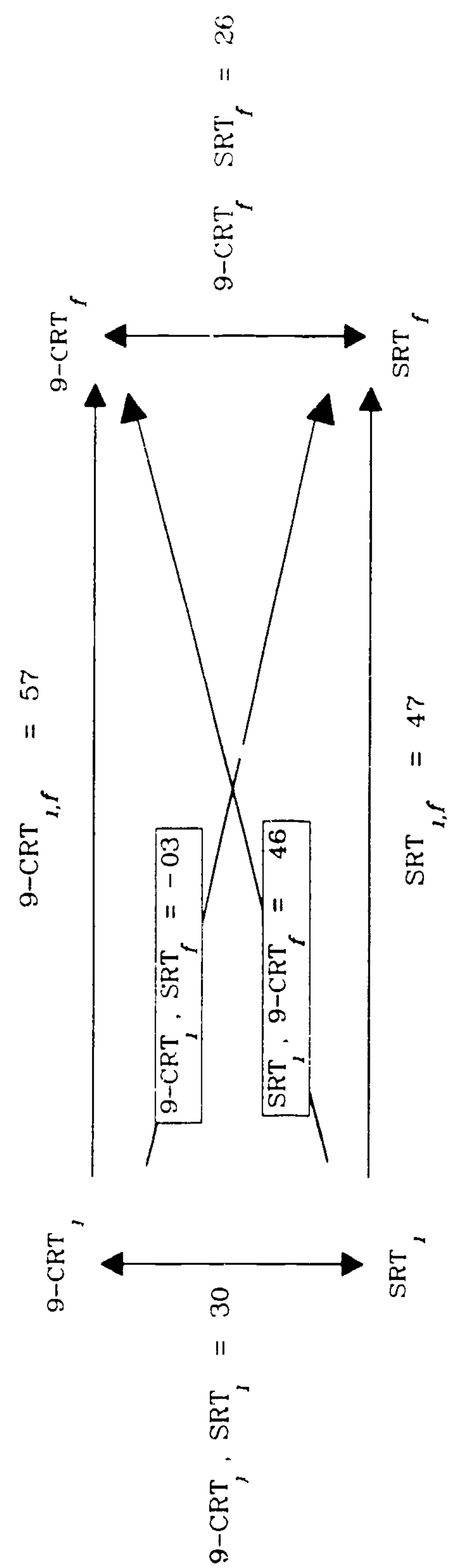

Figure 15. Cross-lagged and synchronous correlations for the Nine-Choice RT and Simple-RT practice tasks. i = initial, f = final, 9-CRT = Nine-Choice RT, SRT = Simple RT. Note the strong asymmetry between the cross-lagged correlations (the diagonal arrows), with the initial Simple-RT measure being much more highly correlated with the final Nine-Choice RT measure than the converse pair.

serve a mediational role as determinants of skilled performance across differing tasks.

The increasing communality found among several perceptual speed and ATC performance measures over practice further suggests that average transfer estimates must be predicated on the similarity of abilities that are required for performance of the respective training and transfer tasks. It may be hypothesized that transfer of skill is more likely to occur for tasks that call for the same underlying abilities (at skilled performance levels) than for tasks that do not share underlying ability determinants of performance. Furthermore, individuals who have lower levels of such abilities will likely show less transfer than individuals of higher abilities, ceteris paribus. The present findings and implications are consistent with previous theorizing by Sullivan and his colleagues relating general intelligence to broad transfer contexts, such as analogical reasoning (Skanes, Sullivan, Rowe, & Shannon, 1974; Sullivan, 1964). The cognitive ability - skilled performance theoretical framework proposed by Ackerman (1988), and extended in this report goes beyond the earlier perspectives provided by Adams (1953) and Fleishman and Rich (1963) in a way that may allow for integration of individual differences and general transfer issues.

The results shown in this report also strongly argue against many traditional measures of transfer for assessment of skill specificity, especially for procedural knowledge. Given that transfer tasks may demand some early components of skill acquisition at initial transfer, overlap of procedural skills will not be reflected at initial transfer, but rather subsequent to practice on the transfer task. Thus, a more informative assessment of skill specificity may likely take place in the examination of later stages of skilled performance on the transfer task.

The purpose of Experiment 3 was three-fold: (a) to empirically demonstrate, via the use of an individual-differences approach, the limitations of skill specificity claims in the literature (especially as they pertain to individual differences); (b) to further validate a theory of the cognitive ability determinants of procedural learning: and (c) to provide a pre- and post-practice sampling of perceptual speed measures in comparison to individual differences in the acquisition of a complex procedural skill.

Although no one experiment is sufficient to disconfirm a theory, the present empirical study has demonstrated that as a procedural skill was acquired, some independent ability measures increased in communality -- a direct contradiction of the skill specificity hypothesis. Such results offer further support for Adams' (1987) optimism regarding the falsity of the skill specificity hypothesis, in terms of predicting individual differences in skilled performance from measures that are independent of the criterion task (p.56). Furthermore, the predictions relating to ability determinants of individual differences in skill acquisition derived from Ackerman (1988) were generally consistent with the obtained data, especially for the well-defined Choice and Simple RT tasks. After practice with these tasks, patterns of individual differences in performance were not only increasingly more similar (an increase in communality), but, with the exception of the Simple-RT task, the measures increased in communality with post-practice individual differences in the more complex ATC task. As the three other measures of perceptual speed indicated, there is a clear need for further information processing modeling of these traditional measures, so that additional linkages can to be drawn between the disciplines of experimental and correlational psychology. Finally, this investigation suggests that an aptitude-treatment interaction approach represents a fruitful direction for further investigation of the general issues of specificity of learning and transfer.

Ramifications and Conclusions

Domain of the theory revisited

To this point a limited variety of tasks have been reviewed. In accordance with the definition of skills presented in the early part of this report, each of the experiments made use of tasks that depended to a substantial degree on motor behavior. Even so, a wide variety of other motor behaviors can be subsumed by the Adams (1987) definition, such as tracking, aircraft piloting, playing musical instruments, and so on. The theory, though, is intended to also subsume performance in these other instantiations, as long as the components can be proceduralized (in line with the Anderson [1983] and Shiffrin & Schneider [1977] theories of learning). Skills such as chess mastery or physics problem solving do not depend to any significant degree on motor behavior, and as such are not expected to follow the ability-performance transitions outlined in this theory.

For logistic (and theoretical) reasons, highly complex tasks were not considered here. The logistic reasons pertained to the need for training times within the time allowed for the subject samples. Generalization to tasks that, for example, require twenty or more hours for a transition between skill acquisition phases to occur should be straightforward, though other variables may have obscuring effects. Prominent among such variables is motivation. When tasks are simple, and training time is short, the demands for perseveration are relatively small. Longer training times will surely exacerbate different effort allocations to performance improvement and maintenance, especially under attention-intensive controlled processing conditions (see Kanfer, 1987, Kanfer & Ackerman, 1989, for discussion of some of these effects).

However, as tasks become complex enough to preclude initially successful performance among all members of the subject sample, Pearson product-moment correlations are no longer universally appropriate measures of ability-performance associations. Discontinuity in the distribution brings a need for data transformation, or alternative measures of covariation (e.g., non-linear correlation); for a discussion of such issues see Carroll (1961). In such cases, though, one might contrast the subjects who can at least do the task, albeit slowly, with those subjects who cannot do the task correctly at all, early in skill acquisition.

Intelligence and Skill Acquisition

Does this theory answer the perennial question about whether intelligence represents the ability to learn? If the essence of learning is characterized as representing those processes underlying Phase 1, that is, formulation of production systems that allow a task to be performed, the answer is yes. However, if learning is defined by some achievement index (i.e., some final, asymptotic performance level attained), a more qualified answer seems necessary. To the degree that the skill acquisition tasks discussed here are those within the ability repertoire of nearly all members of the subject population (albeit with different levels of initial performance), general intelligence does *not* limit final level of skilled performance. Instead, other, less general abilities determine individual differences at skill Phase 3. Thus, for simple, consistent tasks that are often found in military and industrial settings, it should come as no surprise that job performance individual differences are only moderately correlated with general intelligence (Ghiselli, 1966). The abilities that predict

performance in consistent tasks decisively change during skill acquisition. However, when tasks are not consistent, or are so complex to preclude initial successful performance, less attenuation of general ability-performance correlations is predicted, and indeed, has been found (see discussion in Ackerman, 1989, and Schmidt, Hunter, Outerbridge, & Goff, 1988).

Sternberg (1985) suggests that learning tasks measure "novelty-coping skills earlier during practice and automatization skills later during practice" (p. 77). To the degree that general and broad content abilities can be identified with such "novelty-coping" abilities, the current formulation is consistent with aspects of Sternberg's triarchic theory. Similarly "automatization skills" may be identified with the perceptual speed ability described in this report. Questions about the particulars of these abilities or skills await in-depth investigation from a cognitive-components perspective.

However, the theory and data presented here also point to potential solutions to the problems of predicting performance at various stages of task proficiency. An analysis of the major moderating influences of skill acquisition (namely consistency and complexity) provides for predictions of what abilities limit performance during training. Coupled with evaluation of between-subject variability levels during training, this information can be further used to provide diagnostic information about (a) why individuals wash-out of training, and (b) what aspects of a training program are preventing (or facilitating) the normal phase transitions of skill acquisition.

Transfer and Abilities

A further question of interest regards the interplay between the acquisition of skills and changes in ability levels (Alvares & Hulin, 1972; Corballis, 1965; Ferguson, 1956). Previous discussions have been oriented to whether the underlying nature of the task changes or abilities of learners change with task practice. From the skill acquisition perspective, it is clear that as the learner progresses from Phase 1 to Phase 3 the character of information processing undergoes rather profound changes. How these changes feed back to ability changes is less clear.

The current theory indicates that different abilities are involved at each of the three stages of skill acquisition. Thus, one possibility is that, during Phase 3, any potential impact on the general ability will be minimal. Otherwise, ability transfer (i.e., increment in the ability in question) is expected to occur in parallel to the current phase of skill acquisition. During Phase 1, successful formulations of efficient production systems *might* result in improvements in general ability. Phase 2 processing might result in improvements to perceptual speed ability, and so on. However, given the broad nature of the general ability, such improvements resulting from the acquisition of a single skill will probably remain relatively small. Although decisive experiments that address this issue are not available, training and transfer data (such as those of Pellegrino, 1983, and by Sullivan, 1964) are consistent with this inference.

PART V. CURRENT AND FUTURE DIRECTIONS

Current and future research involves a three-pronged approach to the integration of ability and information processing skill perspectives is presented. This approach has the following foci: (1) To continue the investigation of ability-skill relations for tasks that depend on consistent perceptual/motor skill development; (2) To extend the

theoretical framework and empirical base to acquisition of skills that require forms of more pure cognitive skills, for example, complex problem solving skills that are required in heuristic-decision making, strategy selection, information integration; and (3) To investigate ability-skill relations during acquisition of skills that require fine motor coordination, for example, as required in tasks performed by laboratory technicians, medical and dental personnel, and some microelectronic equipment maintenance fields. The general approach to learning and individual differences is expected to lead to a further unification of ability-based and information-processing based frameworks for individual differences in skill acquisition, and to provide a combined theoretical-empirical basis for ultimate application to selection and training programs for technical skills.

PART VI. REFERENCES

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PART VII. PUBLICATIONS, PAPERS, AND RELATED ACTIVITIES

PUBLICATIONS

Ackerman, P. L. (1986). Skill acquisition, individual differences and human abilities. *Proceedings of the 30th annual meeting of the Human Factors Society*, 270-274.

Abstract

The nature of individual differences in novel and practiced performance on skill acquisition tasks is considered from an information processing framework that incorporates concepts derived from automatic/controlled processing and attentional resource perspectives. A set of skill acquisition experiments graphically demonstrate changes in individual differences parameters via manipulating task characteristics of 1) information processing consistency, 2) memory load, 3) stimulus novelty. A further experiment illustrates the effects of novel, but consistent information processing demands on abilities, within a transfer-of-training paradigm. Results are discussed in the context of ability/skill relations.

Ackerman, P. L. (1987). Individual differences in skill learning: An integration of psychometric and information processing perspectives. *Psychological Bulletin, 102*, 3-27.

Abstract

The nature of individual differences in novel and practiced performance on skill learning tasks is reexamined from an information processing framework that incorporates concepts derived from automatic/controlled information processing and attentional resources perspectives. Also, developments in quantitative analysis procedures are utilized to approach previous data in a single, unbiased framework for evaluation. Two major sources of data and discussion are reanalyzed and critically evaluated. One source concerns the changes in between-subject performance variability with task practice. The other main source of data and theory pertains to associations between intellectual abilities and task performance during skill acquisition.

Early studies of practice and variability yielded mixed results regarding the convergence/divergence of individual differences with practice. Other studies regarding intelligence and skill learning indicated small or trivial correlations between individual differences in intelligence and 'gain' scores. More recent studies indicated small correlations between performance measures on skill learning tasks and standard intellectual/cognitive ability measures, as well as increasing amounts of task-specific variance over learning trials. On the basis of this reanalysis and reexamination, these data confirm the proposition that individuals converge on performance as tasks become less dependent on attentional resources with practice. Further, it is determined th when appropriate methodological techniques are used and crucial task characteristics are taken into account, intellectual abilities play a substantial part in determining individual differences in skill learning.

Ackerman, P. L. (1987). Intelligence. Chapter in S. C. Shapiro (Ed.) *Encyclopedia of Artificial Intelligence. Volume 1.* (pp. 431-440). New York: Wiley.

Abstract

Modern, systematic study of intelligence began in the mid 1800s. The first such work was conducted by Sir Francis Galton. Galton's view of intelligence was that it distinguished those individuals who had genius (e.g., demonstrated by making contributions to science, literature, art) from normal individuals. His thesis was that men of genius had sense of insight, a better command of knowledge, and so on. Given an assumption that all knowledge must be processed by the senses (such as by sight, hearing), those individuals demonstrating genius must have more refined sensory and motor faculties. Thus, Galton argued, intelligence could be measured by assessing constructs such as visual acuity, reaction time, pitch discrimination and the like. However, even though a great volume of data was collected on the psychophysical abilities of individuals, no evidence for a general association of genius with those abilities was found.

A great amount of attention (something on the order of 7,000 articles and books were published on intelligence as of 1968) has been given to defining, describing, predicting, and understanding human intelligence in the hundred years since Galton's early investigation of the concept. Early research in this century was primarily devoted to examining intelligence as a single broad construct. More recent study has focused on particular facets and components of intelligence. Several threads of thought have consistently remained central to these investigations. These fundamental issues and findings are discussed in detail.

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117*, 288-318.

Abstract

An integrative theory is presented that links general models of skill acquisition with ability determinants of individual differences in performance. Three major patterns of individual differences during skill acquisition are considered: changes in between-subject variability, the simplex pattern of trial intercorrelations, and changing ability/performance correlations with practice. In addition to a review of previous theory and data, eight experimental manipulations are used to evaluate the cognitive ability demands associated with different levels of information processing complexity and consistency. Subjects practiced category word search, spatial figure, and choice reaction-time tasks over several hundred trials of task practice. An air-traffic controller simulation was used to show generalization to a complex task. Examinations of practice-related between-subject variance changes and ability/performance correlations are used to demonstrate that an equivalence exists between three broad phases of skill acquisition and three cognitive/intellectual determinants of individual differences.

Ackerman, P. L., & Kanfer, R. (1988). Declarative and procedural knowledge in skill acquisition: An aptitude - treatment interaction framework for training. *Proceedings of the 32nd annual meeting of the Human Factors Society*, 1241-1245.

Abstract

This paper focuses on the interactions among four constructs during skill acquisition: (1) the dynamic changes in attentional demands of the task to be acquired, (2) individual differences in cognitive and intellectual abilities, (3) conative (motivational), metacognitive processes involved in changes of attentional focus, and (4) knowledge structures acquired through part-task training. An attentional model is reviewed that describes how these variables interact during three phases of skill acquisition (i.e., during declarative knowledge, knowledge compilation, and at the level of proceduralized knowledge). Empirical demonstration of the framework is provided in the context of complex skill acquisition. Supportive results from a series of empirical studies are reviewed.

Ackerman, P. L., & Sager, C. E. (1988). Cognitive/intellectual abilities as predictors of skilled performance: Answering the which, when, and how questions. *Proceedings of the 32nd annual meeting of the Human Factors Society*, 1006-1010.

Abstract

Recently, there has been a re-emergence of interest in the cognitive ability determinants of individual differences in skill acquisition and skilled performance. First we review some basic characteristics of individual differences in skill acquisition. We next consider the current evidence for the emergent "task-specific" factor, a matter that may have important implications for the utility of ability measures as predictors of individual differences in asymptotic skilled performance. We also review two major factors in determining the relations between abilities and individual differences in skill acquisition, advances in theory and the enlargement of the data base for discussion of the topic. We address these factors, in the context of a discussion of "which" abilities predict individual differences in skilled performance, "when" such predictors are maximally effective, and "how" abilities and information processing demands interact to determine ability-performance associations.

Ackerman, P. L. (1989). Individual differences and skill acquisition. In P. L. Ackerman, R. J. Sternberg, & R. Glaser (Eds.). *Learning and individual differences: Advances in theory and research* (pp. 165-217). New York: W. H. Freeman.

Abstract

The chapter is divided into *four* parts. The first part reviews approaches to individual differences in skill acquisition that were under consideration in 1967. The discussion is coupled with a description of developments in the intervening 20 years.

The second part of this chapter is devoted to brief reviews of (a) a modern, general approach to skill acquisition: (b) a recently developed structure of abilities for skill acquisition; and (c) a proposed theory of individual differences in skill acquisition that unifies these two paradigms. The third part of the chapter contains a review of empirical studies that focus on the proposed theory of individual differences in skill acquisition. Finally, the fourth section of the chapter concerns the implications of the theory and data for future research in individual differences in learning, and for other, related research areas.

Ackerman, P. L. (1989). Within-task intercorrelations of skilled performance: Implications for predicting individual differences? *Journal of Applied Psychology, 74,* 360-364.

Abstract

Recent discussion by Henry and Hulin (1987) about the implications of stability and change in skilled performance are questionable on several counts. First, the presentation reflects an inadequate review of previous data pertaining to the influences of skill acquisition on ability-performance covariance. In addition the authors made untenable assumptions that equate ability with job sample measures. Their conclusions about universal decline in predictive validity coefficients are inconsistent with both theory and data in the literature. As a result, misleading generalizations were made to other issues in the prediction of individual differences. This article notes deviations from historical literature and outlines the problems of this approach. In addition, discussion of theoretical frameworks for predicting individual differences in skill acquisition and skilled performance is presented, along with an overview of data in support of these frameworks. The conclusions reached from this review differ from those of Henry and Hulin (1987) and lead to different interpretations of past research and practice as well as proposing very different directions for future research.

Kanfer, R., & Ackerman, P. L. (1989). Motivation and cognitive abilities: An integrative/aptitude-treatment interaction approach to skill acquisition. *Journal of Applied Psychology - Monograph, 74,* 657-690.

Abstract

Two central constructs of applied psychology, those of motivation and cognitive ability, are integrated within an information processing perspective. We begin with a conceptual framework for simultaneous consideration of individual differences in cognitive abilities and volitional/self-regulatory processes of motivation. From this framework, we propose that motivational interventions (i.e., goal setting) specifically interact with abilities and task demands. Empirical demonstration of the framework is provided in the context of skill acquisition, where the information processing and ability demands change as a function of practice, training paradigm, and the timing of goal setting. Three skill acquisition-goal setting experiments are reported, in a large scale field-based lab setting. Subjects engaged in complex, computerized, Air Traffic Controller tasks. In the first experiment, the basic learning and ability-performance

parameters of the task were evaluated in conjunction with a goal-setting intervention early in practice. Results offered support for the initial tenets of the framework, and point to a number of critical issues in the appropriate use of goal-setting in a complex learning environment. In Experiment 2, goal setting was further investigated at a later stage of skill acquisition, for demonstration of the interactions between task demands and motivational interventions. The third experiment simultaneously examined the effects of task training content, goal setting, and ability-performance interactions during skill acquisition. Results from this series of experiments support the theoretical framework for interactions among abilities, motivational mechanisms, and information processing demands of task performance. The integrative/aptitude-treatment interaction framework leads to a reconsideration of the basic notions of ability - motivation interactions, and to implications for design of training programs and motivational interventions.

Kanfer, R. & Ackerman, P. L. (1989). Dynamics of skill acquisition: Building a bridge between abilities and motivation. In R. J. Sternberg (Ed.) *Advances in the psychology of human intelligence. Volume 5* (pp. 83-134). Hillsdale, NJ: Lawrence Erlbaum Associates.

Overview

At various points during this century, and especially in recent years, it has been popular to claim that the IQ operationalization of the intelligence construct is an overly restrictive one (e.g., see Gardner, 1983; Guilford, 1967; Sternberg, 1985). Numerous researchers have sought to expand the construct of intelligence beyond the verbal knowledge, reasoning math and spatial ability domains. In general, these researchers have implicitly maintained that a broader definition of intelligence will yield a psychologically richer basis for theorizing about individual differences in person-environment interactions.

The approach described in this chapter takes a altogether different tack for furthering the study of intelligence. Rather than seeking to expand the taxonomic basis of intellectual abilities, our aim is to integrate a more traditional ability approach with another critical family of theories, that is, that of motivational determinants of performance. By presenting a sketch of unified approach to ability and motivation phenomena, we hope to establish a framework that will more firmly ground intelligence theory in a larger context, and will continue to challenge ability theorists towards broader notions of intelligence. That is, we feel that consideration of interactions among the three key psychological classes of individual differences, (1) cognitive (i.e., intellectual), (2) conative (i.e., motivational), and (3) affective, are integral for understanding the development and expression of intelligence.

The forum for this discussion will concern individual differences in skill acquisition. Within this domain, we will discuss the independent and interactive influences of two sets of constructs: ability determinants of individual differences in performance, and motivational interactions with ability and information processing variables. Because this approach integrates traditionally divergent areas, it is necessary to provide a review of the foundation areas and discuss how these areas may be fitted together in an integrative fashion. Sections of this chapter are devoted to the

exposition of each area, along with a sketch of a model for the integration of constructs.

In addition to describing this general framework for individual differences, we illustrate our approach. We describe an investigation of ability/motivation interactions during the acquisition of a moderately complex skill, that of a simulated air traffic controller task. The theoretical and empirical foundation is used to discuss a number of issues salient to intelligence theory and applications, such as the structure and expression of intellectual abilities and the range of potential aptitude - treatment interactions (ATI) for instructional design and organizational training.

Ackerman, P. L. (In press). Abilities, elementary information processes, and other sights to see at the zoo. In R. Kanfer, P. L. Ackerman, & R. Cudeck (Eds.) *Abilities, motivation, and methodology: The Minnesota symposium on learning and individual differences* (pp. 281-293). Hillsdale, NJ: Lawrence Erlbaum Associates.

Abstract

This chapter discusses the historical and modern nature of inquiry into learning and individual differences, and provides commentary on issues raised in accompanying chapters by (a) Pellegrino, Hunt, and Yee, (b) Kyllonen and Woltz, (c) Gustafsson, and (d) Lohman.

Ackerman, P. L., & Humphreys, L. G. (In press). Individual differences theory in industrial and organizational psychology. Chapter to appear in M. D. Dunnette (Ed.) *Handbook of industrial and organizational psychology, Volume 1. Theory in industrial and organizational psychology.* Palo Alto, CA: Consulting Psychologists Press.

Abstract

The logic and tactics of individual differences approaches to industrial and organizational psychology are reviewed and discussed in this chapter. Facets of both interindividual and intraindividual differences are considered. A central theme concerns issues relating to construct validity and ability testing. The importance of construct validity for applications of individual differences theory is extensively discussed. Specific issues addressed include test homogeneity, stability, validity generalization, population characteristics, and the selection of appropriate dependent variables. The importance of cognitive/intellectual ability assessment for industrial and organizational applications is illustrated, within domains of selection, training and classification. We also discuss a dynamic framework for interindividual and intraindividual differences in abilities, in the context of learning and skill acquisition. An overview of group differences research on cognitive abilities is provided, with particular attention to male/female differences and black/white differences as they relate to applied settings.

Ackerman, P. L., Sternberg, R. J., & Glaser, R. (Eds.) (1989). *Learning and individual differences: Advances in theory and research.* New York: W. H. Freeman. ISBN: 0-7167-1985-1 (paper); 0-7167-1983-5 (cloth).

This volume brings the field of learning and individual differences up-to-date in two ways. The first way is through a critical review of progress in the field in the past 20 years. The second way is through presentation and discussion of current, cutting-edge research in the domain of learning and individual differences. The contributors focus on research areas that facilitate the exchange of ideas across different approaches and place each area in historical perspective. Topics discussed in this volume include: (a) practical vs. academic learning, (b) children's strategy use in math learning, (c) individual differences in skill acquisition, (d) aptitude - treatment interactions, (e) a taxonomy of learning skills, and others.

Kanfer, R., Ackerman, P. L., & Cudeck, R. (Eds.) (In press). *Abilities, motivation, and methodology: The Minnesota symposium on learning and individual differences.* Hillsdale, NJ: Lawrence Erlbaum Associates. ISBN: 0-8058-0495-1 (cloth), 0-8058-0496-X (paper).

This volume contains the proceedings of The Minnesota Symposium on Learning and Individual Differences held at the University of Minnesota on April 16-18, 1988. The book is divided into five parts, and encompasses not only prepared papers that were presented at the symposium, but compiled and edited transcriptions that took place at the symposium. *Part I* provides an orientation to the treatment of learning and individual differences from three major perspectives: experimental psychology, motivational psychology, and differential/methodological psychology. *Part II* continues and expands the discussion of quantitative methodology and applications to learning and individual differences. *Part III* is devoted primarily to developments in the cognitive ability domain, while *Part IV* addresses the impact of noncognitive, personal constructs on learning and performance. The volume concludes with *Part V*, which discusses transitions in the field, and closing remarks about the conference.

Sytsma, M. R., & Ackerman, P. L. (1987, August). *Abilities for skill acquisition: A study of perceptual speed.* Paper presented at the annual meeting of the American Psychological Association, New York.

Abstract

The present study examined the factorial composition of Perceptual Speed and its relationship to performance on three discrimination reaction time tasks. Seventy subjects completed a battery of 18 tests and the three reaction time tasks. A Schmid-Leiman hierarchical factor analysis yielded a second order General/Spatial ability factor and three first-order factors: Spatial, Non-Spatial Perceptual Speed, and Verbal Abilities. On average, females scored higher on tests defining the Non-Spatial Perceptual Speed factor and males performed better on tests defining both spatial factors (General/Spatial and Spatial Ability). The relations between these factors and the 4 and 9 choice reaction time tasks were consistent with the predictions of Ackerman's (1986, 1987, 1988) theory of abilities and skill acquisition.

This study continues a series of investigations concerning the nature of fundamental ability determinants of performance during skill acquisition. Clarifying the nature of these determinants of performance during training may enable researchers and practitioners to enhance selection assessment procedures. That is, measures of fundamental abilities can be used as diagnostic tools for selection, especially for jobs crucially dependent on perceptual/motor skills.

Ackerman, P. L. (1987, September). *"Ability to Benefit:" An individual differences perspective.* Invited address presented at the U.S. Department of Education, Office of Student Financial Assistance Roundtable on "Ability to Benefit." Leesburg, Virginia.

Abstract

I. Overview

This paper discusses several issues concerning individual differences and "ability to benefit" in post-secondary study. The first issue concerns a simple fact, that is, different skills have different ability requirements. Next, I discuss the range and distribution of ability in our population, and the impact that ability has on educational success and occupational attainment. Then, I demonstrate the substantial impact that ability testing has on our educational and industrial sectors. I also spend some time specifically discussing the potential impact for post-secondary institutions when ability tests are used for admission purposes. In addition, I discuss how individual differences in abilities interact with types of educational curricula; and finally, I outline a few recommendations for educational admissions programs on the basis of this individual differences perspective.

Ackerman, P. L. (1989, March). *Cognitive abilities, skill learning, and transfer of training.* Symposium paper presented at the 1989 annual meeting of the American Educational Research Association, San Francisco, CA.

Abstract

The objectives of this research program are to discover and to understand the cognitive ability determinants of individual differences in skill learning. In particular, investigations have focused on the relations between three central ability classes (general intellectual, perceptual speed, and psychomotor) and individual differences in skill acquisition. Recently, the approach has been expanded to investigate aptitude - treatment interactions regarding learning and transfer of training during skill acquisition. Ferguson's (1956) and Sullivan's (1964) hypotheses regarding the relationship between intellectual ability differences and the distance of transfer (near vs. far) are discussed in the context of an attention-based theory of the ability determinants of skill acquisition (e.g., Ackerman, 1988; Kanfer & Ackerman, in press). Experiments of simple information processing tasks (e.g., choice reaction time, and memory search) are integrated with acquisition of more complex rule-based tasks (e.g., the Kanfer-Ackerman Air Traffic Controller). Subject populations include high school students, college students, and military trainees. Implications for tailored training/instructional programs are discussed from an ability-performance relations perspective.

Ackerman, P. L. (1989, August). *Abilities and individual differences in skill acquisition: Theory and applications.* Invited address (Divisions 21 & 1) presented at the annual meeting of the American Psychological Association, New Orleans. Cassette tape available from American Psychological Association, #89-02.

Abstract

The study of individual differences in skill acquisition has an extensive history. Many influential modern psychologists have studied this topic directly, including E.L. Thorndike, H. Woodrow, E.A. Fleishman, G.A. Ferguson, R.M. Gagné, and L.J. Cronbach. Many other psychologists have addressed this domain indirectly as well, through work in methodology and statistics. The historical interest stems from the fundamental importance this topic has for numerous basic and applied concerns. This presentation reviews the theoretical and applied progress in this field, from both historical and modern perspectives. Several developments in the integration of differential psychology and cognitive information-processing psychology domains are discussed. In addition, the results of an empirical research program concerning cognitive abilities and individual differences in the acquisition of perceptual-motor skills are presented. Prospects for basic theory and applications are discussed with respect to: (a) development of more accurate instruments for the prediction of employment training success; (b) identification of optimal instructional or training methods for particular classes of individuals (such as adaptive training and intelligent tutoring); (c) the development of more accurate theories of learning and (d) advances in the understanding of the development and expression of intellectual abilities.

Ackerman, P. L. (1989, August). *A correlational analysis of skill specificity: Learning, abilities, and individual differences*. Working paper 89-08. Department of Psychology, University of Minnesota, Minneapolis, MN.

Abstract

The current investigation uses a dynamic ability-skill perspective to evaluate how individual differences in procedural learning for a criterion task relate to learning of procedures for other tasks. A theoretical approach to this issue is reviewed, based on the cognitive ability determinants of skill acquisition. An experiment with 86 college students was performed, using a simulated air traffic control task for assessment of procedural learning, along with practice on several perceptual speed measures, and assessment of general and perceptual speed reference abilities. Discussion is devoted to the dynamic changes in communality among consistent tasks that allow for development of automaticity, to the lack of specificity of individual differences in developed skills, and the use of individual differences approaches to address general transfer and skill specificity issues.

RELATED RESEARCH ACTIVITY

U S. Navy Personnel Research & Development Center. "*Proposal to Investigate the Effect of Practice on the Validity of Spatial Tests.*" (with D. F. Lohman, Co-Principal Investigator, University of Iowa). 9/88-3/90.

Overview of Project

Based on the initial basic research sponsored by ONR described above, an applied set of studies was initiated, in conjunction with the U.S. Navy Personnel Research & Development Center. This project involves the investigation of three issues related to the effects of practice on the validity of spatial tests: (a) Type of Feedback, (b) Amount of Practice; and (c) Validity and Practice. The project is on-going at this date.

Minnesota Symposium on Learning and Individual Differences: Abilities, Motivation, and Methodology

This conference was part of the University of Minnesota Graduate School's Centenary symposia series; it was jointly sponsored by the College of Liberal Arts, the Graduate School, and by a $15,000 grant from the Office of Naval Research/Navy Personnel Research and Development Center. The conference was designed to bring together people interested in three distinct, but related research perspectives for the purpose of advancing knowledge about learning and individual differences. Scholars from Europe, Scandinavia, and the United States served as invited speakers and discussants. In addition, over 60 local, national, and international observers attended the symposium. Proceedings from this conference are compiled in a volume to be published October, 1989 by Lawrence Erlbaum Associates.

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