Journal of Experimental Psychology:
Learning, Memory, and Cognition
1990, Vol. 16, No. 5, 883-901

0278-7393/90/$00.75

A Correlational Analysis of Skill Specificity: Learning, Abilities, and Individual Differences

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Skill specificity, the notion that task performance is based on unique underlying information-processing components at skilled levels of performance, is examined from the perspective of the ability determinants of individual differences in task performance during skill acquisition. The current investigation uses a dynamic ability-skill theoretical perspective to evaluate how individual differences in procedural learning for a complex criterion task relate to learning of procedures for other more basic tasks such as choice and simple reaction time. An experiment with 86 college students was performed using a simulated Air Traffic Controller (ATC) task for assessment of procedural learning, along with practice on several perceptual speed measures and assessment of reference abilities. When subjects are allowed to practice tests of perceptual speed and psychomotor ability, some measures increase in their power to predict skilled performance on the complex ATC criterion task, a direct disconfirmation of the skill-specificity thesis. Discussion is devoted to the use of individual-differences approaches to address general transfer and skill specificity issues.

The specificity of learning has been an issue of considerable importance to the field of experimental psychology throughout this century, from the early discussions of transfer of training by Thorndike and Woodworth (1901) to more modern treatments by Singley and Anderson (1989) or Lehman, Lempert, and Nisbett (1988). The issue has been a focus of both traditional transfer-of-training experiments (e.g., see Adams, 1987, for a review), and individual-differences experiments (e.g., for an early study, see Buxton & Humphreys, 1935; for a review, see Marteniuk, 1974). Although the approaches are different—one being predominantly experimental, the other correlational—the questions have been similar. Specifically, how much of developed skills is specific to the task at hand, and how much is generalizable to other tasks? *Skill specificity* refers to the uniqueness of basic information-processing components underlying task performance or, from an individual-differences perspective, the uniqueness of the ability determinants of individual differences in task performance. In the context of transfer, the presence of skill specificity in an initial task would lead to a lack of impact on the performance of a transfer task.

Many training and transfer procedures have been used within experimental psychology (see Gagné, Forster, & Crowley, 1948; for a recent review, see Singley & Anderson, 1989). The research question often evaluated in such studies is whether training on some task has an impact on performance (or learning) of some transfer task. A wide range of divergent and sometimes contradictory results has been demonstrated for such studies, partly because of methodological difficulties and partly because of inconsistencies across investigations in the definition of *transfer*. Where some results indicate significant transfer for both simple and complex tasks, other results indicate an overwhelming lack of transfer (Singley & Anderson, 1989).

Results previously obtained using correlational approaches have been similarly cloudy, mainly because of methodological problems in assessing individual differences in the degree of learning in any task. On the one hand, at the level of broad abilities, substantial correlations are found between general intellectual abilities and performance of a variety of novel, broad-content tasks (e.g., Horn & Cattell, 1966). On the other hand, the correlations between abilities and performance on relatively narrow tasks tend to be much more modest. In fact, for skills that predominantly require perceptual and motor responses from subjects, much of the research to date has encountered difficulties in discovering abilities that predict individual differences at highly skilled levels of performance (Fleishman, 1972). Such results were once typically used for speculation that skilled performance is highly specific to individual tasks. If it were not specific, so the argument went, abilities that are assessed independently of the criterion task should be able to predict such individual differences in asymptotic performance. Such arguments have quite often been made in the motor learning domain (e.g., see reviews by Kleinman, 1983; Marteniuk, 1974). However, given recent methodological advances and reanalyses of the literature, it is not clear that such claims of skill specificity are justified on the basis of the corpus of data (Ackerman, 1987; Adams, 1987).

Going beyond the surface levels of similarity between the constructs of skill specificity (individual differences perspec-

This research was supported by Contracts N00014-86-K-0478 and N00014-89-J-1974 from the Office of Naval Research, Cognitive Science Program.

Portions of the data reported in this article were presented at the 1989 annual meeting of the American Educational Research Association.

I gratefully acknowledge many insightful suggestions by Jack A. Adams and two anonymous reviewers of this article.

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tive) and transfer of training (experimental perspective) is a problem of unifying nomological frameworks and experimental paradigms. It is not clear from the literature that such skill specificity correlations and transfer measures are determined by the same underlying mechanisms, or that they are directly tied together at all. However, one investigator (Sullivan, 1964) suggested that degree of transfer from one task to another is a function of general intellectual ability level and distance of transfer. That is, Sullivan's hypothesis was that high-ability learners show proportionally greater transfer in distant-transfer conditions, and that low-ability learners show proportionally greater transfer in near-transfer conditions. In a sense, this was a hypothesis that fundamentally relates transfer with skill specificity; distance of transfer could be indexed by traditional transfer measures, and intellectual ability was hypothesized to correlate positively with amount of transfer in distant-transfer conditions and correlate negatively with amount of transfer in near-transfer conditions. Although Sullivan demonstrated the generality of intellectual ability for transfer, he did not directly address issues of the specificity of ability determinants of performance across various tasks.

The current investigation takes one part of the issue, namely, an examination of the dynamic characteristics of individual differences in performance as procedural skills are acquired. From this perspective, comparisons are made between individual differences in performance at various stages of practice on multiple learning tasks in an effort to test the existence of skill specificity across tasks. To put the literature and current perspective into context, this introduction first focuses on historical discussions and empirical investigations of the issue of skill specificity from an individual differences perspective. Next, the theoretical basis for the current investigation is presented, along with a description of how this individual-differences theory is integrated with current experimental approaches to skill acquisition. Finally, the implications of the theory for skill specificity research are extrapolated to provide the specific basis for the current empirical investigation.

Previous Studies

Over the past two decades, a reconsideration of the literature concerning individual differences in learning has occurred (e.g., see Cronbach & Furby, 1970; Cronbach & Snow, 1977). The reason for this reconsideration is that much of the older research was based on the use of gain scores to indicate learning (e.g., Woodrow, 1946). Such measures are now known to yield spurious results with respect to individual differences in learning.

However, there are a few strictly correlational studies that provide data relevant to the current concerns. Buxton and Humphreys (1935) examined the developmental aspects of skill specificity by giving subjects practice on two motor learning tasks[1] (Koerth Pursuit Rotor and the Brown Spool Packer). The criteria for skill specificity were the intercorrelations between performance measures on the tasks, at both the beginning and the end of a series of practice sessions extending over three hours and distributed over three days. On the basis of small intercorrelations among tasks, both at initial measurement and after substantial practice, the authors concluded that motor learning is highly specific. That is, how individuals performed on one task had little to do with how they performed on the other task. Buxton and Humphreys argued that no general factor was found to underlie complex motor skills. In addition, such data also indicated that classification of psychomotor skills in terms of muscles used to perform such tasks did not yield a valid taxonomy of common abilities for skilled performance.

Later studies provided an initial impetus toward considering a more functional or information-processing perspective. Two experiments by Adams (1953, 1957) concerned prediction of individual differences on a Complex Coordination task and a Discrimination Reaction Time (RT) task, respectively. In the initial study, Adams (1953) administered a battery of printed and apparatus tests of perceptual speed and psychomotor abilities, and the criterion task. In addition, many of these tests were administered repeatedly in a practice format. The major thesis put forth by Adams was that the criterion task did not become more specific with practice. Instead, some predictor tests increased in association with performance on the criterion task over task practice. Furthermore, when subjects were allowed to practice on the predictor tests, individual differences in performance on some tests were more highly associated with skilled performance on the criterion task. In fact, it was possible for Adams to derive a multiple regression equation of independent tests that predicted final criterion task performance to a higher degree than did initial measures of performance on the criterion task. A similar conclusion was derived from the second study (Adams, 1957), although the predictor measures were not practiced in that experiment. Adams hypothesized that the integrated nature of skilled performance is similar to an executive control of multiple task components, and that this would be the source of communality among skilled tasks. Regardless of the mechanisms, however, Adams proposed that skills did not necessarily become more specific as they are acquired.

Although Adams' reasoning is plausible, it does not provide a framework by which one may predict which tests will share more or less variance with practice. In addition, such predictions are inconsistent with more recent findings of initially increasing and then decreasing correlations between perceptual speed tests and practice on criterion skill-acquisition tasks (namely, subsequent research by Ackerman, 1987, 1988; Fleishman, 1960; Fleishman & Hempel, 1954, 1955).

Reanalysis of the Adams (1953) data by Fleishman and Hempel (1954) turned out to be equivocal about changes in

[1] Part of the difficulty encountered in integrating experimental and correlational approaches is a difference in terminology regarding learning tasks and ability tests. Correlational psychologists have typically referred to tests rather than tasks even when learning is involved. Experimental psychologists typically refer to tasks regardless of the learning context. Whenever there is some lack of clarity in distinguishing between learning measures and reference ability measures (that are not accorded practice), the present article refers to learning measures as tasks and to reference ability measures as tests. Note that in some cases, those designated tests in the literature have been classified as tasks here.

skill specificity because of statistical artifacts (see Ackerman, 1987, for a review and further reanalyses). However, a later study by Fleishman and Rich (1963) added some credibility to the notion that skill specificity may not increase with task practice. These authors used a two-hand coordination task, and found that a measure of kinesthetic sensitivity increased in correlations with criterion task performance as skills were acquired on the criterion task. Fleishman and Rich hypothesized that the ability to integrate spatial cues is important once the broad spatial information-processing demands of the criterion task are acquired by the subjects. Aside from the further demonstration that some tests increase in correlation with a criterion skill-acquisition task as practice progresses, however, the Fleishman and Rich study does not allow for generalization beyond such spatially demanding tasks.

Recent research on the cognitive ability determinants of skill acquisition has resulted in a theoretical framework relating abilities to performance on tasks as procedural skills are acquired. This framework incorporates a broad information-processing perspective for skill acquisition (based on Anderson, 1982, 1983; Shiffrin & Schneider, 1977), with an integrated structure of cognitive/intellectual abilities (Ackerman, 1988). The theory provides a specification of the relations between abilities and task performance as procedural skills are acquired. Furthermore, the theory implies a structure under which skill specificity may be evaluated from an individual-differences perspective. The current article extrapolates and tests the skill specificity implications of my (Ackerman, 1988) theory and provides an empirical demonstration of the importance of individual-differences considerations for experimental treatment of skill-specificity issues. The theory and its background are briefly reviewed.

Abilities and Task Performance

It is possible to link an abilities perspective with a broad skill-acquisition perspective. The basis for this linkage is the performance-resource function posited by Norman and Bobrow (1975). Norman and Bobrow described resources as portions of a subject's attentive capacity. Previously I (Ackerman, 1984, 1986b, 1987) suggested that individual differences in general intellectual ability may be conceptualized as differences in individuals' total attentional cognitive capacity. As such, the performance-resource function designation may be translated into a performance-ability function.

Given a conceptual mapping from individuals' general intellectual ability to their level of attentional functioning (e.g., see Ackerman, 1986a; Zeaman, 1978), ability differences may be translated into individual differences in attentional resources. From this perspective, differences in task performance attributable to amount of attention allocated to the task will parallel differences in performance attributable to individual differences in level of general cognitive ability-intelligence. Consistent with this perspective is a general correspondence between the attentional requirements of information-processing tasks and the degree of association between general intellectual abilities and task performance (e.g., as evidenced in Kyllonen, 1987).

A Theory of Abilities for Skill Acquisition

On the basis of reviews of the literature and support by a series of empirical studies, I (Ackerman, 1988) proposed that three major ability classes are critically important for predicting individual differences in performance during the three broad phases of skill acquisition as described by several investigators, including, for example, Anderson (1983, 1985).[2] The types of tasks that are subsumed by this approach are those that involve predominantly consistent mapping of stimuli and responses (a criterion described as integral to development of automatic processing and contrasted with variable mapping of stimuli and responses; see Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), and those that are "importantly dependent on motor behavior" (Adams, 1987).

A proposed structure of abilities for skill acquisition is presented in Figure 1. A brief review of the three critical components of the theory follows, but additional details are presented in Ackerman (1988).

Phase 1: Declarative Knowledge and General Intelligence

Declarative knowledge is defined as "knowledge about facts and things" (Anderson, 1985, p. 199). A critical feature of the declarative phase of skill acquisition is the substantial attentional resource demands imposed on the learner. Performance in the declarative knowledge phase is typically slow and error prone. Once the person has come to an adequate cognitive

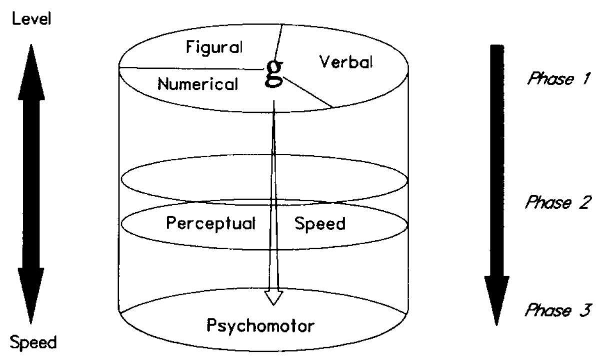

Figure 1. A modified radex-based model of cognitive abilities (g = general ability). From "Determinants of Individual Differences During Skill Acquisition: Cognitive Abilities and Information Processing" by P. L. Ackerman, 1988, *Journal of Experimental Psychology: General, 117,* p. 291. Copyright 1988 by the American Psychological Association. Reprinted by permission

[2] Anderson (1982, 1983) used a production-system perspective to suggest that skill acquisition can be segmented into three phases: declarative knowledge (Phase 1), followed by knowledge compilation (Phase 2), and finally procedural knowledge (Phase 3). This perspective is consistent with the descriptions of skill acquisition proposed by Fitts and Posner (1967) and with that offered by Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977). In the Shiffrin and Schneider framework, these phases of skill acquisition are labeled (a) controlled processing, (b) mixed controlled and automatic processing, and (c) automatic processing.

representation of the task, he or she can proceed to the second stage: the knowledge compilation phase.

The received conception of general intelligence is that it encompasses the individual's repertoire of knowledge and facility with "acquiring, storing in memory, retrieving, combining, comparing, and using in new contexts information and conceptual skills" (Humphreys, 1979, p. 115). This construct is closely related in the nomological network to the information-processing construct of declarative knowledge. Numerous studies have indicated that general abilities (e.g., reasoning) and broad content abilities (such as verbal, numerical, and spatial) predict individual differences in task performance (e.g., Ackerman, 1988; Cronbach & Snow, 1977; Fleishman, 1972). Recent research has also equated a general reasoning ability with individual differences in working memory capacity (Kyllonen & Christal, in press; Kyllonen & Woltz, 1989).

General intellectual abilities appear to be involved in the aspects of task acquisition that make substantial demands on declarative knowledge and, thus, the attentional system. When learners first confront a novel task, the attentional load for them is quite high. When these demands are high, correlations between general intellectual abilities and task performance are also high. As learners begin to understand the demands of the task (via instructions, for example) and derive plans of action for performance, the attentional demands decrease, and the correlations between general intellectual abilities and performance decline. That is, 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, 1986b, 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).

Phase 2: Knowledge Compilation and Perceptual Speed

For tasks that allow for consistent information processing, performance speed and accuracy markedly improve over the course of practice (e.g., see Fisk, Ackerman, & Schneider, 1987; Newell & Rosenbloom, 1981, for reviews). During the knowledge compilation phase of skill acquisition, learners integrate the sequences of cognitive and motor processes required to perform the task. As this compilation occurs for each task component, the declarative knowledge system, and thus the attentional apparatus, is relieved of the productions originally required to perform the task. As such, the attentional load on the learner is reduced as the task objectives and procedures are moved from working memory to long-term memory (Fisk & Schneider, 1983).

A second major component of the ability spectrum is a broad class of perceptual speed abilities. Tests of these abilities (which typically include so-called clerical tests such as Proofreading, Cancelling A's, Digit-Symbol) represent situations where individuals must develop simple procedures for task accomplishment and build them into rapid, accurate, and efficient perceptual and motor programs. It is in tasks where proceduralized knowledge is built and maintained by the learners that abilities in this domain are predictive of individual differences in task performance.

As learners traverse the skill-acquisition curve, moving from the declarative to procedural phases, correlations between perceptual speed abilities and task performance increase even as the correlations between general abilities and performance decline. When learners already have a basic understanding of how to do the task but are seeking more efficient methods for accomplishing it with minimal attentional effort, abilities demanded by the task are similar to those demanded by perceptual speed tests. From this perspective, perceptual speed measures seem to identify those persons who can proceduralize information the fastest or most efficiently (Ackerman, 1988).

Phase 3: Procedural Knowledge and Psychomotor Abilities

Procedural knowledge is defined as "knowledge about how to perform various cognitive activities" (Anderson, 1985, p. 199). This final phase of skill acquisition is reached when the individual has essentially automatized the skill, and the task often can be efficiently performed with little attention. During Phase 3, the skill has been proceduralized such that once a stimulus is presented the responses can often be prepared and executed without conscious mediation by the learner. Although improvements in performance during practice are still found at this final level of skill acquisition, practice functions at this stage are well described in terms of diminishing returns, in keeping with the Power Law of Practice (Newell & Rosenbloom, 1981).

Psychomotor abilities are typically measured in RT and accuracy of simple motor behaviors, such as simple RT, performance on Purdue Pegboard, Rotary Pursuit, Complex Coordination, and other tests that require reduced demands for higher order information processing and increased demands on basic perceptual and motor processes (i.e., minimal demands are made for text processing, semantic memory, problem solving, and so on, and large demands in rapidity of responses; see, e.g., Fleishman, 1954). 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) when minimal stimulus or response uncertainty exists.

As learners move into the procedural phase of skill acquisition, their performance is no longer limited by the speed of proceduralization, but rather by the learner's asymptotic psychomotor speed and accuracy. Thus, individual differences in final skilled performance are not necessarily determined by the same abilities that affect the initial level of task performance or the speed of skill acquisition. Rather psychomotor abilities reflect the processes that limit skilled performance after extensive practice. For the broad sphere of tasks that "importantly depend on motor behavior" (Adams, 1987), psychomotor abilities appear to be significant predictors of individual differences in asymptotic task performance (e.g., Ackerman, 1988; Fleishman & Hempel, 1954, 1955; but see reanalysis by Ackerman, 1987).

The three basic propositions of the theory are as follows: (a) general and broad content abilities are associated with initial task performance; (b) perceptual speed abilities are associated with an intermediate stage of skilled performance; and (c) psychomotor abilities are associated with asymptotic, automatized skilled performance. From these three propositions, the expected pattern of ability–performance relations during skill acquisition for consistent information-processing tasks can be represented as in Figure 2. That is, in the declarative phase of skill acquisition, high correlations between general and broad content abilities and performance are found. As the intermediate stage of skill acquisition is reached, perceptual speed abilities are most associated with individual differences in task performance. Finally, as learners fully proceduralize their knowledge, psychomotor abilities are most associated with task performance. One basic premise of this theory is that individual differences in task performance during skill acquisition reflect more than just general intelligence on the one hand or specific abilities on the other.

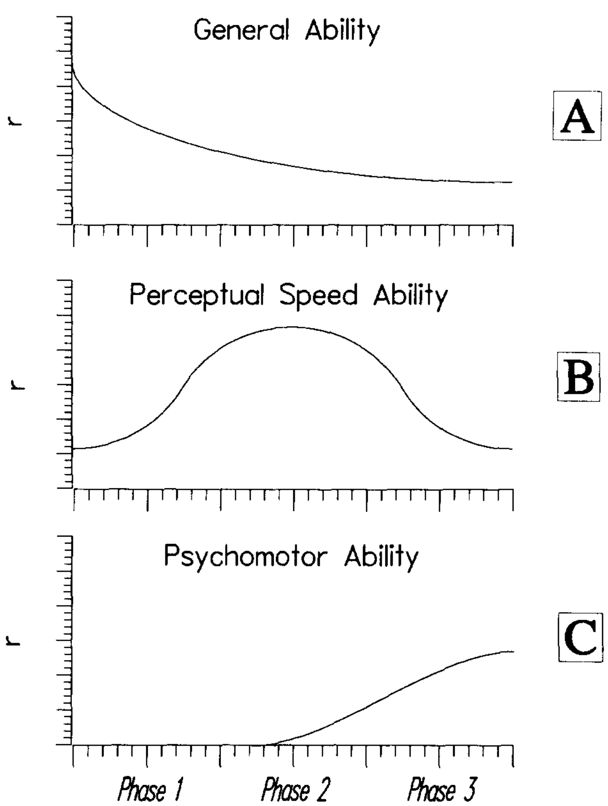

Figure 2. Hypothetical ability-performance correlations during three phases of skill acquisition derived from the framework. (The hypothetical task is moderately complex and provides for consistent information processing. From "Determinants of Individual Differences During Skill Acquisition: Cognitive Abilities and Information Processing" by P. L. Ackerman, 1988, *Journal of Experimental Psychology: General, 117,* p. 294. Copyright 1988 by the American Psychological Association. Reprinted by permission).

Implications of the Theory—A Dynamic Representation of Abilities

The basic framework just presented 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 previously here, 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 initially, and after practice on these measures, should show a temporal shift in the manner depicted in Figure 3. Depending on the phase of skill acquisition on a criterion task and the amount of practice on perceptual speed and psychomotor ability tests, this framework predicts differing degrees of association between ability measures and task-performance measures.

If, as described previously here, skill specificity refers to the uniqueness of the ability determinants of task performance, the theory predicts that skill development will appear to be "specific" only 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). 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.[3] As such, notions of skill specificity can be evaluated from both a static perspective (single testing occasion) and a dynamic perspective (initial test performance and performance subsequent to practice on the tests).

The Current Investigation

The experiment to be described was designed to test the dynamic characteristics of the ability-skill framework proposed previously here and to test the extensions of the theory to the issue of skill specificity. The basic outline for the experiment was first to collect performance data on a complex but consistent criterion task developed by Kanfer and Ackerman (1989) called the Air Traffic Controller (ATC) task. In addition, standard reference battery measures were used to

[3] 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.

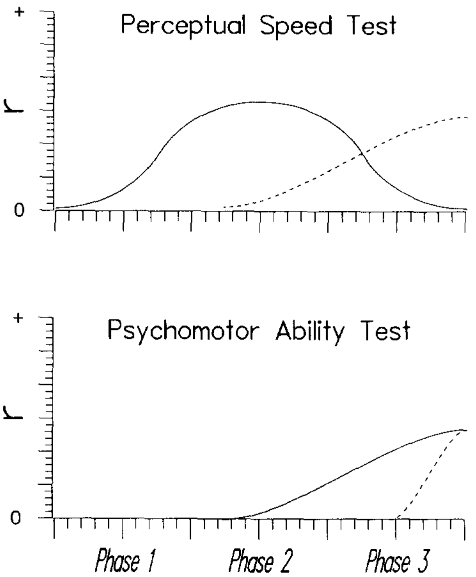

Figure 3. Hypothesized test–task performance correlations during three phases of skill acquisition on criterion task, with dynamic effects of practice on perceptual speed and psychomotor tests on the ability–performance relations. (Solid lines indicate test–task performance correlations based on initial performance on perceptual speed and psychomotor tests. Dotted lines indicate test–task performance correlations based on performance on the same tests subsequent to test practice).

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 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 RT, Four-Choice RT, Two-Choice RT, 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.[4]

The purpose of this current investigation, then, was threefold: (a) to empirically test, using an individual–differences approach, the limitations of skill specificity claims in the literature (especially as they pertain to individual differences); (b) to further test a theory of the cognitive ability determinants of procedural learning; and (c) to provide a dynamic test sampling of perceptual speed measures in comparison to individual differences in the acquisition of a complex procedural skill.

Predictions/Hypotheses

The predictions for the dynamic trends in practice task performance correlations with the criterion skill acquisition task are illustrated in Figure 3 and described explicitly as follows:

First, for tasks identified as measuring perceptual speed, initial task performance is expected to show increasing and then decreasing correlations as practice on the criterion task increases. After practice on the perceptual speed tasks, individual differences in performance on those tasks is predicted to show a shift in ability–performance correlations so as to be more highly associated with late criterion task performance.

Second, for tasks identified as measuring psychomotor ability, initial task performance was expected to show small but increasing correlations with the criterion task practice. After practice on the psychomotor tasks, individual differences in task performance are predicted to have smaller correlations through the early stages of criterion task practice, with increasing correlations late in criterion task practice.

Third, as tasks decrease in complexity (i.e., shift from perceptual speed to psychomotor demands), a shift in patterns from the first to the second prediction is expected.

Method

Subjects

Ninety-four 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 5 hours of participation and $27 for the remaining 5 hours of the experiment. Because of computer failure (affecting 3 subjects) and failure of 5 subjects to follow experimental instructions, data from a total of 8 subjects were incomplete and were thus discarded before analysis. The results reported here were based on data for the 86 subjects with complete data.

Apparatus

For the criterion ATC task, the Choice-RT tasks, and the Simple RT task, instructions, simulation programming and presentation, and response collection were performed with IBM PC computers and with standard keyboards and IBM monochrome display monitors. For paper-and-pencil tests and 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

[4] 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.

time in individual carrels (for the computer-based tasks) and at separate tables (for the paper-and-pencil tests and tasks).

Ability Testing—Reference Tests

To test the theoretical predictions for ability-performance relations as well as demonstrate the ability demands 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 and Accuracy, and Number Sorting). The tests and their sources are described in the Appendix.

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].) The tasks are described in detail in the Appendix. With the exception of the Number Comparison task, each task can be considered as having an underlying consistent mapping of stimuli and responses. 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 (ATC)

Some details of the ATC task have been provided elsewhere in the literature (e.g., Ackerman, 1988; Kanfer & Ackerman, 1989); however, a review of the critical task characteristics is presented here later. A prototypical (albeit static) screen display of the ATC task is presented in Figure 4. 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 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 4, 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 column. Level 1 hold positions have the lowest altitude (i.e., closest to the ground), and Level 3 hold positions have the highest. 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

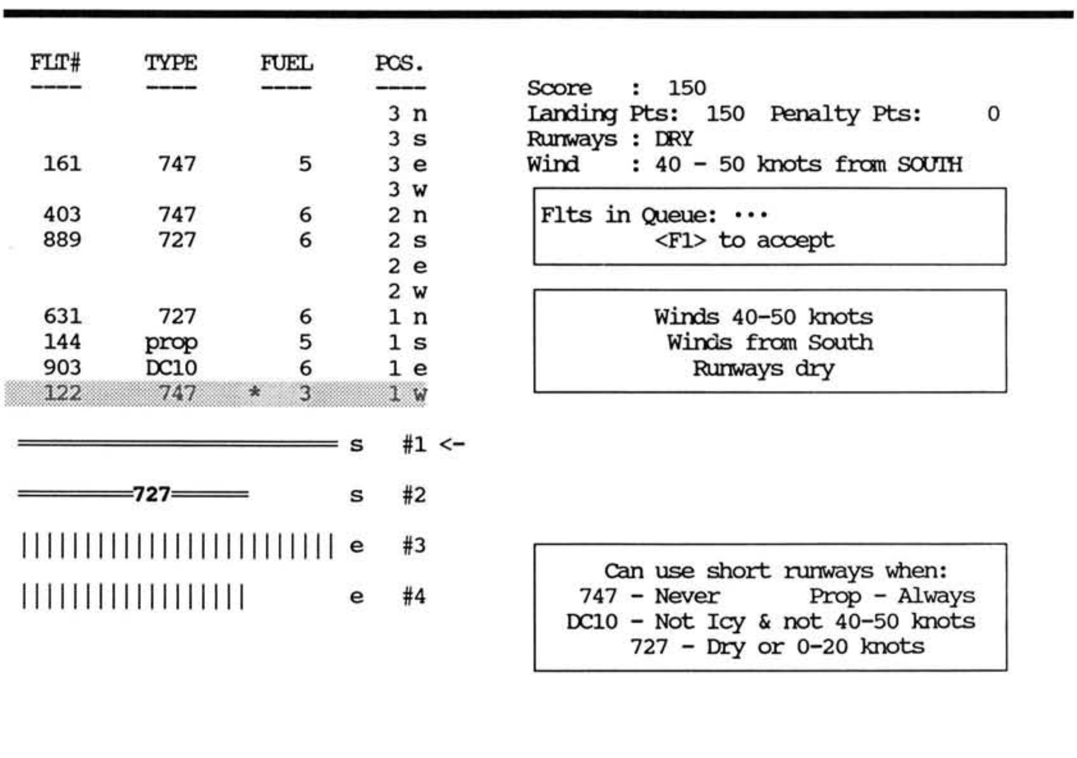

Figure 4. The Kanfer-Ackerman Air Traffic Controller task. (The figure is a literal static representation of the real-time task display. See text for a description of task elements [n = north, s = south, e = east, w = west]. From "Determinants of Individual Differences During Skill Acquisition: Cognitive Abilities and Information Processing" by P. L. Ackerman, 1988, *Journal of Experimental Psychology: General, 117*, p. 308. Copyright 1988 by the American Psychological Association. Reprinted by permission).

queue, located on 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 s. Plane requests remain in the queue until the subject places the plane in the hold pattern.

Informative Feedback

The first component of feedback 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.

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 and an error message is presented on the screen indicating which rule is violated. The rules for this task are presented in Table 1.

Task Requirements

Three principal actions are performed by subjects: (a) accepting planes into the hold pattern, (b) moving planes in the three-level hold pattern, and (c) landing planes on appropriate runways. All three types of operations can be performed through the selective use of four keys on the computer keyboard. (The four keys were those labeled [↑], [↓], [F1] and [↵]. The up-arrow and down-arrow keys were used to move the cursor up and down, respectively; the carriage-return key was used to select a plane or to complete an operation, such as placing or landing a plane; and the F1 key was used to activate the queue.) 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 Figure 4). Successful performance on this task requires knowledge of the rules governing plane movements and landings as well as procedural knowledge about how to initiate plane movements using the computer keys. From a perspective of information-processing requirements, this task can be considered to involve mostly consistent information processing, given the invariance of task rules and stimulus-response mappings. The only critical component of task performance that has uncertainty for the subject is the timing of weather changes, which determine runways that are open for use. Weather changes occurred approximately every 30 s during each task trial. However, the responses to each weather change are consistently mapped.

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. Previous research (e.g., Kanfer & Ackerman, 1989) indicated that the number of planes landed in each task trial is a reliable and valid measure of overall task performance. For the current experiment, this measure is the focus of ability-performance relations described here later.

Procedure

The first session of the experiment began with a set of instructions on the computer for the ATC task. Subjects then performed three 10-min 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 (nine trials) in a day, with interspersed breaks. The sequence for an experimental session was task trials followed in order by ability testing, break, task trials, ability testing, break, and task trials. This procedure was repeated for the second session (separated by 2 days) and partially repeated for the third experiment session (again separated by 2 days). In the third session, however, only two 3-trial ATC sets were administered, for a total of 24 trials of the ATC task (240 min 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 and 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 and Analogies and received practice on Two-Choice RT, Simple RT, and Cancelling A's tasks.[5]

Results

Given the complex and extensive nature of the analyses accorded the data from this experiment, the results have been divided into four sections. The first section includes a test of basic premises regarding the ATC criterion task and the reference ability–performance measures. In this section, means and standard deviations are reported for the ATC task over practice sessions, along with correlations between the reference ability factors and task performance over practice. The second section provides descriptive statistics regarding the effects of practice on the practice tasks (including the Choice-RT and Simple RT tasks and the three standard perceptual speed tasks). These statistics are examined in comparison to theoretical expectations regarding the effects of underlying consistent information-processing requirements. The third section represents the main test of the theory predictions (i.e., a comparison of correlations between practice task performance and the ATC task performance over practice on both sets of tasks). The fourth section of the results is devoted to an exploratory extension of the adopted meth-

[5] The use of a fixed presentation order for all subjects simplifies the interpretation of the correlational measures at the cost of an inability to determine order effects. That is, although a Latin-square design would have distributed order effects across the conditions, it could have introduced a carryover confound in terms of interactions among learning and abilities occurring in the various practice tasks. However, because positive transfer-of-training could be expected among the Choice-RT and Simple-RT tasks (given similarities in stimuli and responses), it was decided to administer an initial two-block sequence of each task before further practice on the tasks. In this way, the initial measures would be minimally affected by transfer, and the later blocks of performance could be compared with the initial blocks for any indications of transfer effects.

Table 1
List of Operational Rules for Air Traffic Controller Task

Rule 1	Planes must land into the wind. (That is, if the wind is from the south, the plane must be landed on a n-s runway.)
Rule 2	Planes can only land from Level 1.
Rule 3	Planes in the hold pattern can only move one level at a time, but to any available position in that level.
Rule 4	Ground conditions and wind speed determine the runway length required by different plane types. (All planes can use long runways.) In particular; (a) 747s always require long runways; (b) DC10s can use short runways only when runways are dry or wet and wind speed is less than 40 knots; (c) 727s can use short runways only when the runways are dry or wind speed is 0–20 knots; (d) Props can always use short runways.
Rule 5	Planes with less than 3 min fuel left must be landed immediately.
Rule 6	Only one plane at a time can occupy a runway.

Note. From "Motivation and Cognitive Abilities: An Integrative/Aptitude–Treatment Interaction Approach to Skill Acquisition" by R. Kanfer and P. L. Ackerman, 1989, *Journal of Applied Psychology Monograph, 74,* p. 667. Copyright 1989 by the American Psychological Association. Adapted by permission.

odology to consideration of the practice tasks as criterion tasks.

Section I: ATC Criterion Task—Means, Standard Deviations, and Ability–Task Performance Correlations

For the ATC criterion task, performance[6] shows an unequivocal improvement with task practice, and the expected reduction in between-subject standard deviations ($M_{\text{Session 1}}$ = 22.19 s, $SD_{\text{Session 1}}$ = 8.82 s; $M_{\text{Session 8}}$ = 9.87 s, $SD_{\text{Session 8}}$ = 1.35 s). These effects are shown graphically, across the entire set of practice sessions, in Figure 5. Reductions of both means and standard deviations are significant; for means, $F(7, 595) = 158.64$, $p < .01$; for *SD*s, $t(85)$, 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., Newell & Rosenbloom, 1981).

The inclusion of the seven reference ability tests in this experiment was to provide necessary baseline information regarding the dynamic changes in ability determinants of ATC task performance during task practice. To provide this demonstration, it was necessary to derive estimates of general and perceptual speed abilities that could be correlated with ATC task performance. Because spurious factor loadings result from a simultaneous factor analysis of reference-ability and task-performance measures, it is generally useful to follow a two-step procedure. The first step is to derive a factor solution for the reference battery and then to mathematically "extend" the factor solution to determine the correlations between the reference factors and the practice data. For a detailed discussion of this procedure, see Humphreys (1960; also, see Ackerman, 1986b, 1987).

Mean, standard deviation, and reliability estimates are provided for the seven reference ability tests in Table 2. These indicators are consistent with earlier uses of the measures (e.g., see Ackerman, 1986b, 1988).

The seven reference tests used as markers for general ability (denoted *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.[7] The intercorrelations among the tests and the factor solution are presented in Table 3 and Table 4, respectively. 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.

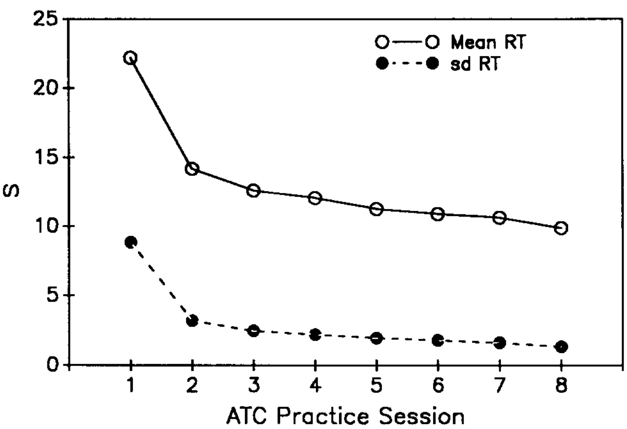

Figure 5. Mean reaction time (RT) (across subjects and practice sessions) and between-subject standard deviation (*SD*) measures as a function of practice on the Air Traffic Controller (ATC) task. Each session of practice contained three 10-min trials).

[6] For the criterion task performance measure (planes landed) and for all other practice task measures, if raw scores were 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 the same ratio scale of measurement. Such measures indicate the amount of time taken to complete one item correctly.

[7] Although a hierarchical factor solution could be computed, given the small number of tests and factors, and the relative simple structure resulting from the varimax rotation, the first-order factors were viewed as an appropriate level of abstraction for the current purposes.

Table 2
Descriptive Statistics for Reference Ability Tests

Test	*M*	*SD*	Reliability[a]
Clerical Speed and Accuracy	103.55	18.57	.92
Perceptual Speed	54.16	8.94	—
Number Sort	30.07	9.12	.91
Letter Sets	20.55	4.94	.68
Raven Progressive Matrices	34.80	6.73	.75
Figure Classification	115.74	36.03	.84
Analogies	31.34	4.97	—

[a] Reliability estimates based on Part I/Part II correlations and the Spearman-Brown formula. Perceptual Speed and Analogies only had one part each; thus, no reliability measures were computed.

Table 4
Reference Factor Solution

Test	Factor I	Factor II
Clerical Speed and Accuracy	.050	.774[a]
Perceptual Speed	.216	.519[a]
Number Sort	.273	.492[a]
Letter Sets	.620[a]	.078
Raven Progressive Matrices	.777[a]	.250
Figure Classification	.472[a]	.286
Analogies	.484[a]	.133

[a] Factor loadings greater than .300.

The last step in determining ability-performance correlations was to mathematically extend the factor solution to include the ATC task performance measures using a procedure derived by Dwyer (1937). These correlations are presented in Figure 6. Such results map closely to those expected from the theory and from previous results with this task (e.g., Kanfer & Ackerman, 1989). As predicted, Session 1 performance individual differences were most associated with *g*, with declining correlations over task practice, $R^2_{\text{cubic}} = .69$, $F(3, 4) = 3.00$, $p > .05$.[8] 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, and leveled off at the end of the allowed practice period, $R^2_{\text{cubic}} = .91$, $F(3, 4) = 13.24$, $p < .05$. 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 nonsignificant) 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. These results provide additional support for the theory outlined in Ackerman (1988) and, more critically, provide the basis for using the ATC task as a criterion for dynamic ability–criterion performance relations considered in Sections III and IV.

Section II. Practice Tasks

Descriptive statistics for the practice tasks are presented in Table 5. For each task, both initial (Block 1/Part 1) and final (Block 12/Part 10) means and standard deviations are shown, along with differences between the two and their intercorrelations.[9] 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 standard deviation.[10] With

Table 3
Reference Battery Intercorrelations[a]

Test	1	2	3	4	5	6	7
1. Clerical Speed and 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	

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

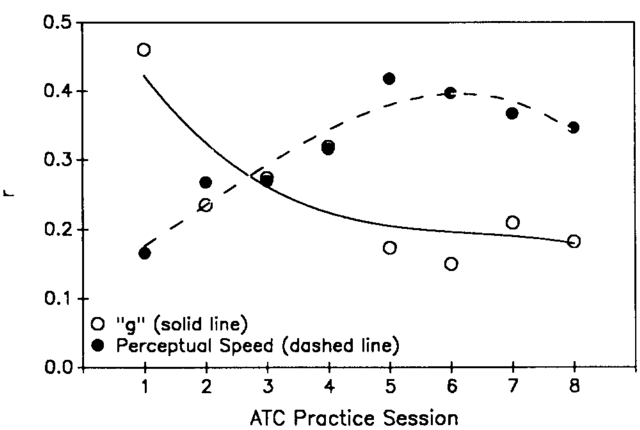

Figure 6. Ability–performance relations for the Air Traffic Controller (ATC) task. Correlations between task performance and derived General (*g*) and Perceptual Speed abilities. (Solid line indicates regression of General ability [cubic polynomial] loadings over practice. Dotted line indicates regression of Perceptual Speed [cubic polynomial] loadings over practice.)

[8] Adequacy of curve fits are reported for each ability–performance curve. Given the rather small number of points (8) plotted for each curve as a result of averaging over ATC task trials, however, overinterpretation of the standard .05 alpha criterion for Type I errors (adopted here) runs a substantial risk of ignoring Type II errors. Thus, R^2 for curve fits are reported, in addition to the standard *F* test results, for comparison purposes.

[9] Because of limited space, the entire set of reference test, practice task, and ATC criterion correlations are not included here. However, a paper or disk copy of the full intercorrelation matrix may be obtained directly from Phillip L. Ackerman.

[10] It turned out that there was little direct positive transfer across these tasks. Analysis of performance changes from the second trial block (given at experiment Session 1) and the third trial block (given at later experimental sessions) indicated very little performance improvement beyond what would have been expected from a continuous

Table 5
Descriptive Statistics for Practice Tasks

Task	Block 1		Block 12				
	M	*SD*	*M*	*SD*	$M_1 - M_{12}$	$SD_1 - SD_{12}$	$r_{1,12}$
Nine-choice RT	909	158	653	101	256**	57**	.57**
Four-choice RT	580	90	558	85	22*	5	.41**
Two-choice RT	403	75	376	46	27**	29**	.37**
Simple RT	265	40	265	50	0	−10**	.47**
	Part 1		Part 10				
	M	*SD*	*M*	*SD*			
Letter/Number Substitution	1,382	232	1,406	258	−24	−26	.43**
Number Comparison	3,141	618	2,752	670	389**	−52	.39**
Cancelling A's	2,392	666	2,123	531	269**	135**	.87**

Note. Numbers are in milliseconds, except for correlations in last column. RT = reaction time.
* $p \le .05$. ** $p \le .01$.

the exception of the Letter/Number Substitution and Simple RT tasks, all others indicated significant reductions in mean RT with practice. Four tasks—Nine-Choice RT, Four-Choice RT, Two-Choice RT, and Cancelling A's—showed significant reductions in between-subject standard deviation. 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. Although 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, e.g., the discussion by Stroud, 1955). As such, this would make up 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.

Although these results do not preclude testing of the theoretical predications regarding skill specificity and practice, they do highlight the fact that these tasks, although often considered to represent perceptual speed (or psychomotor ability), are not identical in reactivity to practice. The departures from general improvement (and reduction in interindividual variability) were expected a priori in the case of the Number Comparison task but not in the Letter/Number Substitution or Simple RT tasks.

Although the seven interoccasion intercorrelation matrices are not presented here because of space considerations, as with the criterion task and indeed all multioccasion data, these intercorrelations showed the simplex-like ordering; the largest values were found in the adjacent correlations, and declining correlations were found with increasing occasion differences. In general, the smallest intercorrelations were found between the initial and final trials of each task. 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.

Section III. Ability–Performance Correlations—Initial Performance/Postpractice

The critical results for evaluating the theory and the skill-specificity hypothesis are the initial and postpractice patterns of ability–task performance/ATC performance relations. For the sake of brevity, only the first and last measures for the practice tasks are used for this set of analyses (e.g., Trial Blocks 1 and 12 for the Choice-RT tasks). Because these measures provide the most extreme amounts of practice, such data make for the clearest evaluation of the hypotheses. (In fact, the intermediate practice results reveal intermediate patterns between the initial and final data.)

The three predictions for the dynamic trends in practice task performance correlations with the criterion ATC task were described earlier and, as illustrated in Figure 3, pertained to (a) Perceptual Speed tasks–criterion task performance relations; (b) Psychomotor task–criterion task relations; and (c) the role of task complexity in determining the shift from perceptual speed to psychomotor demands.

Figure 7 shows the correlations between the eight ATC practice-session performance measures with Block 1 task performance and Block 12 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 3.[11]

series of trials for each task. Improvements in mean performance levels from Block 2 to Block 3 were as follows: Nine-Choice RT (28 ms), Four-Choice RT (36 ms), Two-Choice RT (18 ms), Simple RT (29 ms).

[11] 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, whereas tests of average correlation differences would obscure any apparent interaction effects. Tests of the regression estimates (e.g., trend analysis) for such curves do not provide a ready solution either, because the individual data points are correlations rather than individual observations (for ex-

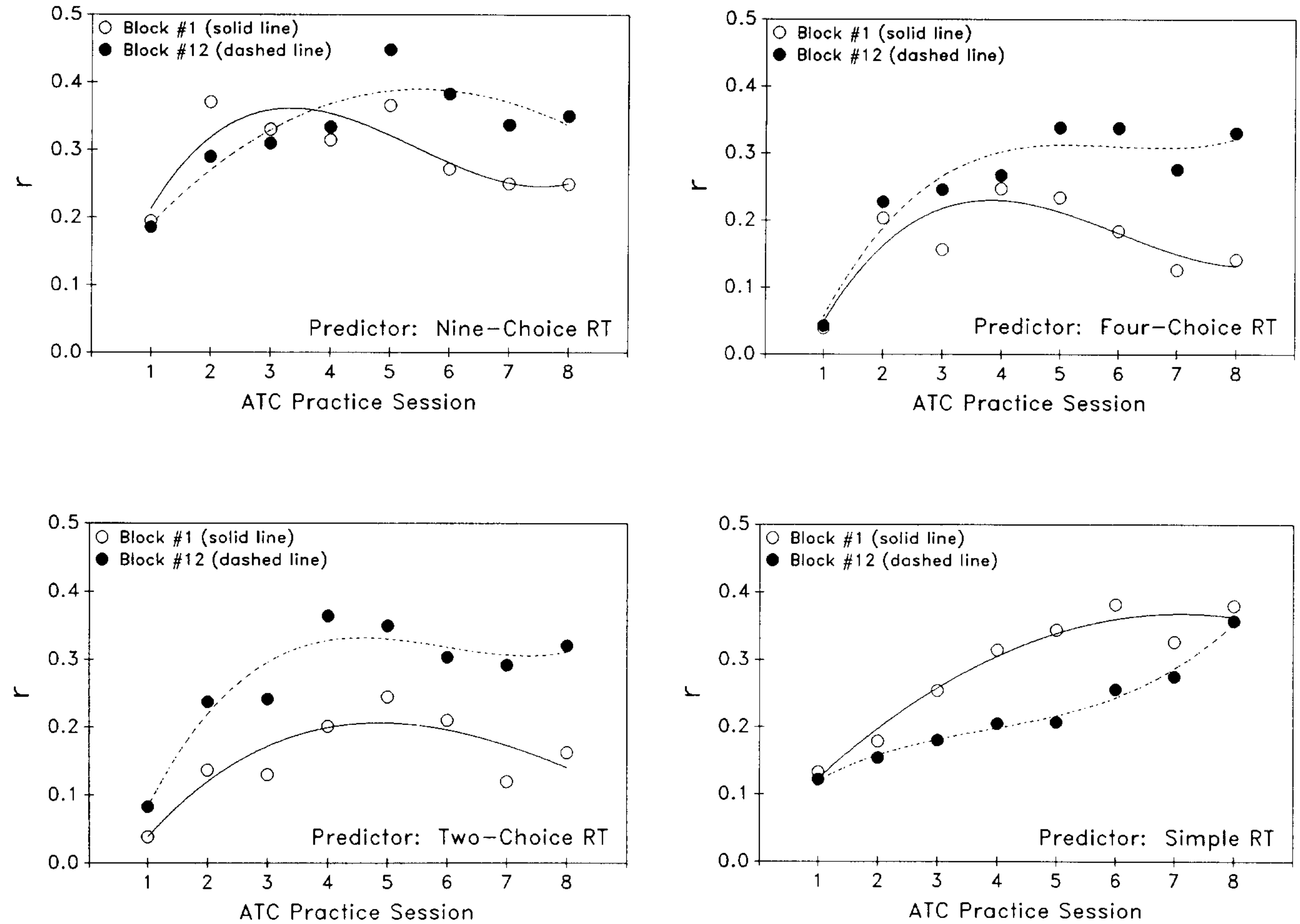

Figure 7. Ability test–performance relations for the Air Traffic Controller (ATC) task as a function of practice on Nine-Choice Reaction Time (RT), Four-Choice RT, Two-Choice RT, and Simple RT tasks and practice on the ATC task. (Solid lines indicate cubic polynomial regression of initial occasion task performance [Trial Block 1] on ATC task performance. Dashed lines indicate cubic polynomial regression of last occasion task performance [Trial Block 12] on ATC task performance.)

Block 1 task performance measures for the Nine-Choice, Four-Choice, and Two-Choice RT tasks indicate low correlations with early criterion task performance, with increasing and then decreasing correlations as criterion task practice continued.[12] Block 12 task performance, however, showed larger correlations with the criterion task as criterion task practice continued. For these Choice-RT tasks, Block 12 task performance correlations are larger with final criterion task performance (i.e., higher than Block 1 task performance–criterion task correlations).

amples, see Ackerman, 1988). Nonetheless, the differences between these curves pass both the less precise "interocular impact test" as well as less elegant nonparametric 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 seven or all eight of the pairs differ in the same direction.) For the data presented in Figures 8 and 9, 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.

The Simple RT task shows a pattern of results consistent with its classification as a psychomotor ability (see the predictions in Figure 3). That is, even for Block 1 task performance, 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 Block 12 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.

In addition, as task complexity decreases (from Nine-Choice RT to Simple RT), a shift in Block 1 measure corre-

[12] Fit statistics for the curves plotted in Figure 8 are as follows: Nine-Choice RT Block 1, $R^2_{cubic} = .72$, $F(3, 4) = 3.46$, $p > .05$; Nine-Choice RT Block 12, $R^2_{cubic} = .82$, $F(3, 4) = 6.28$, $p > .05$; Four-Choice RT Block 1, $R^2_{cubic} = .78$, $F(3, 4) = 4.69$, $p > .05$; Four-Choice RT Block 12, $R^2_{cubic} = .91$, $F(3, 4) = 13.44$, $p < .05$; Two-Choice RT Block 1, $R^2_{cubic} = .76$, $F(3, 4) = 4.13$, $p > .05$; Two-Choice RT Block 12, $R^2_{cubic} = .90$, $F(3, 4) = 12.30$, $p < .05$; Simple RT Block 1, $R^2_{cubic} = .95$, $F(3, 4) = 25.07$, $p < .01$; Simple RT Block 12, $R^2_{cubic} = .99$, $F(3, 4) = 115.35$, $p < .01$.

lations from that expected for Perceptual Speed to Psychomotor ability measures is shown. For Block 12 measures, the shift is also apparent, and all of the measures show more similarity to Psychomotor ability measure predictions than to those of Perceptual Speed measures.

For the other three perceptual speed practice tasks, Part 1 and Part 10 practice task–criterion task performance correlations are presented in Figure 8. These curves illustrate both similarities and striking differences from the choice-RT measures just described. First, the higher initial correlations obtained in the Part 1 Letter/Number Substitution task show the strong memory component associated with the task. In fact, this task behaves very much like the measures of g (see Figure 6); the largest correlations are at the initial sessions of criterion task performance, $R^2_{\text{cubic}} = .95$, $F(3, 4) = 27.27$, $p < .01$. However, after practice on the Letter/Number Substitution task, the correlations with the ATC criterion task follow the pattern that would be expected of a perceptual speed test, although the pattern was somewhat noisy, $R^2_{\text{cubic}} = .47$, $F(3, 4) = 1.18$, $p > .05$.

The number Comparison task 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), $R^2_{\text{cubic}} = .63$, $F(3, 4) = 2.28$, $p > .05$. However, increasing task practice results in less communality with the criterion task performance, $R^2_{\text{cubic}} = .86$, $F(3, 4) = 8.46$, $p < .05$, which might be attributed to the lack of stimulus–response consistency in this practice task.

The highly simple and consistent Cancelling A's task behaves mostly like a psychomotor test (e.g., the Simple RT task), both in the Part 1, $R^2_{\text{cubic}} = .98$, $F(3, 4) = 34.06$, $p < .01$, and Part 10, $R^2_{\text{cubic}} = .95$, $F(3, 4) = 23.28$, $p < .01$, 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 results only 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 here.

Overall, five of the practice tasks show decisive increases in association with criterion task performance (Nine-Choice RT, Four-Choice RT, Two-Choice RT, Simple RT, and 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 Two-Choice RT) show additional increases in association with the late criterion task performance after substantial practice was given on those practice tasks.[13]

Section IV. Cross-Correlations Between Practice Tasks

From an exploratory point of view, another way to index the degree of skill specificity, although on a much shorter time–practice scale, is to examine intercorrelations among the practice tasks. That is, the same initial–postpractice analysis can be used, designating the practice tasks as the to-be-predicted criteria. When tasks show increases in correlation (or communality) with postpractice 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 with perceptual speed abilities).

For this analysis, only the choice-RT and Simple RT tasks are considered, because they are most tractable in terms of their differential requirements for information processing. On the basis of this theory and its extensions discussed earlier, and on the differences in complexity among these four tasks, the hypotheses generated for these data are as follows:

1. The initial correlations between tasks will show an approximate simplex pattern when ordered in terms of complexity (i.e., the tasks that are closest in terms of complexity; e.g., Nine-Choice RT with Four-Choice RT) and will have higher correlations than tasks that are more distant in terms of complexity (e.g., Nine-Choice RT with Simple RT).
2. These tasks will show higher intercorrelations at the last block of practice (when the theory suggests that individual differences in performance are primarily due to the same psychomotor ability) than at the first block of practice (when the Nine-Choice RT task is more associated with Perceptual Speed, and the Simple RT task is more associated with Psychomotor ability).
3. Given the change in underlying ability determinants of performance (from Perceptual Speed to Psychomotor ability) in the Nine-Choice RT and Four-Choice RT tasks (and the Two-Choice RT, to a more limited degree), postpractice performance (Block 12) on these measures will be more highly associated with initial performance (Block 1) on the simpler psychomotor tasks (e.g., Two-Choice RT and especially Simple RT) than the converse (late performance on the Psychomotor measures correlated with initial performance on the predominantly Perceptual Speed measures), when maximum construct differentiation occurs.

To evaluate these hypotheses, four sets of correlations are of interest: namely, the synchronous cross-correlations for initial (Block 1) and final (Block 12) tasks and the cross-lagged correlations between the tasks.[14] These correlations are

[13] One potential disadvantage of the fixed presentation order of testing (interspersed with practice on the ATC task) was the influence of temporal proximity on individual differences in performance on the various sets of measures. Although this is a possible hypothesis for the patterns of data discussed to this point, this factor seems to have had a relatively minor role, given the patterns of results obtained in the experiment. For example, the marker tests for the Perceptual Speed factor (Clerical Speed and Accuracy, Perceptual Speed, and Number Sorting) were all administered during the first day of ATC task practice (Sessions 1–3). However, the correlations between the Perceptual Speed factor and task performance increased through Session 5 (the second day of the experiment), and at the final sessions (7 and 8) (the third day of the experiment) were still larger in magnitude than the values for Sessions 1 to 3.

[14] *Synchronous cross-correlations* refer to the correlations between tests with roughly the same amount of practice. For example, the correlation between the Nine-Choice RT task (Block 1) and the Four-Choice RT task (Block 1) represents a synchronous cross-correlation. *Cross-lagged correlations* refer to the correlations between tests for

presented in Table 6 and Table 7, respectively. Although the individual synchronous correlations do not significantly differ from one another, a striking trend emerges from examination of the correlations for the Choice-RT and Simple RT tasks. This trend is that the Choice-RT and Simple RT measures show higher communality at Block 12 than at Block 1. Although this is apparent by contrasting the initial and post-practice synchronous correlations in Table 6, more precise estimates of communality were computed by using a multiple correlation procedure. For the Choice-RT and Simple RT tasks, average communality among these measures was $R^2 = .30$ before practice and $R^2 = .42$ after practice, $t(6) = 5.68$, $p < .05$.

The cross-lagged correlations shown in Table 7 address the consequences of practice upon the nature of perceptual speed/psychomotor task performance. In particular, the significant differences in cross-lagged coefficients found for the Nine-Choice RT and Simple RT and for the Four-Choice RT and Simple RT pairings (and the nonsignificant but similar trend for the Two-Choice RT and Simple RT pair) support the basic premises of the theory and the hypotheses just presented. That is, these cross-lagged correlations show that late performance on the Nine-Choice RT, the Four-Choice RT, and to a nonsignificant degree the Two-Choice RT has more to do with early 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). The other cross-lagged comparisons are not decisive one way or the other (no significant differences in correlations), but this is not surprising in that they are intermediate conditions to the Nine-Choice/Simple RT contrast and the Four-Choice/Simple RT contrast. Again, these results support the theoretical predictions shown in Figure 3, 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 9.

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

different amounts of practice. For example, the correlation between the first block of trials on the Nine-Choice RT (Block 1) and the last block of trials for the Four-Choice RT (Block 12) represents a cross-lagged correlation.

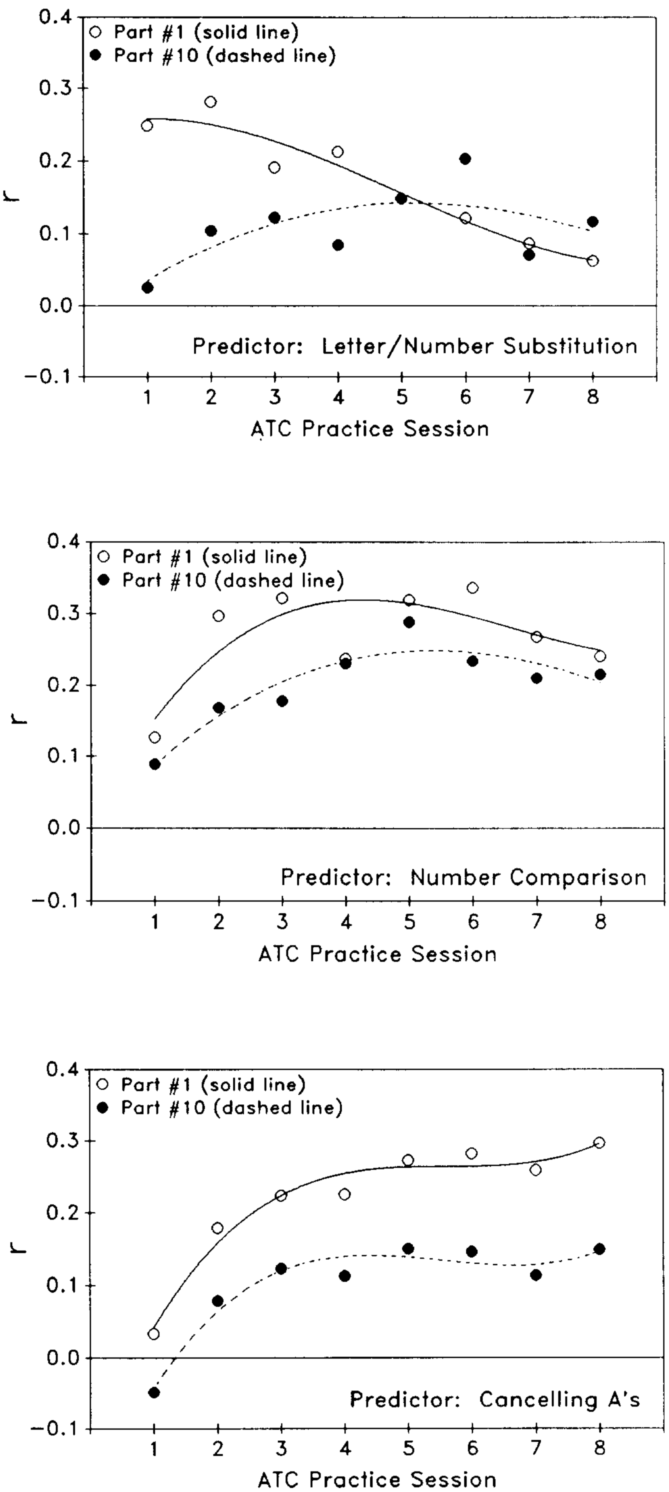

Figure 8. Ability–performance relations for the Air Traffic Controller (ATC) task as a function of practice on Letter/Number Substitution, Number Comparison, and Cancelling A's tasks and practice on the ATC task. (Solid lines indicate cubic polynomial regression of first occasion task performance [Part 1] on ATC task performance. Dashed lines indicate cubic polynomial regression of last occasion task performance [Part 10] on ATC task performance).

Table 6
Synchronous Correlations Among Choice-RT and Simple RT Tasks[a]

Practice tasks	Task 1	2	3	4
1. Nine-choice RT	—	.65	.45	.26
2. Four-choice RT	.59	—	.56	.43
3. Two-choice RT	.25	.42	—	.48
4. Simple RT	.30	.32	.37	—

Note. Block 1 is below diagonal; Block 12 is above diagonal. RT = reaction time.
[a] Individual correlations larger than $r = .183$ are significant at $p \leq .05$, one-tailed.

standard deviations with task practice, and 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 postpractice perceptual speed task measures appear to jointly reflect psychomotor abilities, but they concomitantly showed increases in communality with each other and with practice 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 initial and postpractice correlations would actually become exacerbated—further support for the theoretical predictions.

Although there is no current theoretical basis for directly linking task communality with transfer, the framework presented here may be used to suggest that some linkage is indeed possible. The findings obtained here potentially 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 serve a mediational role as determinants of skilled performance across differing tasks. Thus, transfer effects may be attenuated or exacerbated, depending on the ability levels of the subject sample (as suggested by Sullivan, 1964), but also to the degree that the training and transfer tasks require similar abilities.

The increasing communality found among several perceptual speed and ATC performance measures over practice further suggests that average transfer estimates might be predicated on the similarity of abilities that are required for performance of the respective training and transfer tasks. One speculation is 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 Ferguson (1956) and with theory and data from 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 article 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 dynamic perspective presented here describes changes in the ability determinants of task performance at various stages of skill acquisition. From this perspective, training and transfer situations can be delineated into those that allow for same-stage transfer or for different-stage transfer. Same-stage transfer, for example, would involve general abilities as central determinants of performance for both training and transfer tasks (both tasks at the initial stage of skill acquisition) or psychomotor ability determinants of performance for both tasks. On the other hand, different-stage transfer might involve general abilities as central determinants of training task performance and perceptual speed abilities as central determinants of transfer task performance. The inference from the current perspective (and building on Sullivan's work) is that increased communality will occur for general ability measures with distant transfer task performance (especially when the distant transfer requires acquisition of new declarative knowledge—a same-stage transfer). However, communality will decrease between initial measures of training task performance (or general abilities) and transfer task performance, when near transfer is considered (a situation that is likely to involve transfer of specific procedural task components), and when the absolute amount of transfer will be maximized. Under such conditions, performance measures taken late in practice on the training task will be more predictive of measures taken early in transfer task practice.

Communality among individual-differences measures in transfer will thus be a function of (a) the distance of transfer, (b) the type of knowledge being transferred (i.e., declarative or procedural), and (c) the stage of skill acquisition/type of ability (e.g., general, perceptual speed, or psychomotor) underlying task performance on the training and transfer tasks. By considering both the average degree of transfer and the changes in communality of performance measures (or external markers of the abilities underlying the three stages of skill acquisition), an integrated approach to understanding the mechanisms of transfer may be effected.

Table 7
Cross-Lagged Correlations Among Choice RT and Simple RT Practice Tasks

$r(9\text{-}CRT_{\text{Block 1}}, 4\text{-CRT}_{\text{Block 12}}) = .44$	$r(4\text{-CRT}_{\text{Block 1}}, 9\text{-CRT}_{\text{Block 12}}) = .37$
$r(9\text{-}CRT_{\text{Block 1}}, 2\text{-CRT}_{\text{Block 12}}) = .26$	$r(2\text{-CRT}_{\text{Block 1}}, 9\text{-CRT}_{\text{Block 12}}) = .25$
$r(9\text{-}CRT_{\text{Block 1}}, 1\text{-RT}_{\text{Block 12}}) = -.03^{*}$	$r(1\text{-RT}_{\text{Block 1}}, 9\text{-CRT}_{\text{Block 12}}) = .46^{*}$
$r(4\text{-CRT}_{\text{Block 1}}, 2\text{-CRT}_{\text{Block 12}}) = .32$	$r(2\text{-CRT}_{\text{Block 1}}, 4\text{-CRT}_{\text{Block 12}}) = .18$
$r(4\text{-CRT}_{\text{Block 1}}, 1\text{-RT}_{\text{Block 12}}) = .01^{*}$	$r(1\text{-RT}_{\text{Block 1}}, 4\text{-CRT}_{\text{Block 12}}) = .46^{*}$
$r(2\text{-CRT}_{\text{Block 1}}, 1\text{-RT}_{\text{Block 12}}) = .24$	$r(1\text{-RT}_{\text{Block 1}}, 2\text{-CRT}_{\text{Block 12}}) = .40$

Note. 9-CRT = Nine-Choice Reaction Time; 4-CRT = Four-Choice Reaction Time; 2-CRT = Two-Choice Reaction Time; 1-RT = Simple Reaction Time.
Pairs with asterisks are significantly different from one another; $p \leq .01$, two tailed. Individual correlations larger than $r = .183$ are significant at $p \leq .05$, one-tailed.

Conclusion

The purpose of the current investigation was threefold: (a) to empirically test, by using an individual-differences approach, the limitations of skill specificity claims in the literature (especially as they pertain to individual differences); (b) to further test a theory of the cognitive ability determinants of procedural learning; and (c) to provide an initial and postpractice 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-RT 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 postpractice 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 be drawn between the disciplines of experimental and correlational psychology. Finally, when this study is considered in the light of previous experimental studies of transfer, it seems clear that combined experimental (treatment) and individual-differences (aptitude) approaches may provide information that simultaneously address both the specificity and transfer issues within a single paradigm (commonly referred to as an aptitude–treatment interaction design; see Cronbach, 1957, 1975; Underwood, 1975, for discussions of the tactics of such approaches).

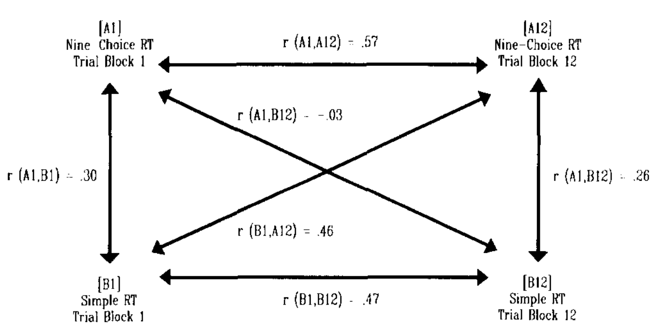

Figure 9. Cross-lagged (diagonal arrows) and synchronous (vertical) correlations for the Nine-Choice Reaction Time (RT) and Simple RT practice tasks. (Note the strong asymmetry between the cross-lagged correlations; the Simple RT Block 1 measure is much more highly correlated with the Nine-Choice RT Block 12 measure than the converse pair).

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Appendix

Reference Tests and Practice Tasks

Reference Tests

Clerical Speed and Accuracy

This is a test of perceptual matching. Subjects must match a letter/number pair on a test sheet with an identical pair on a response sheet and then place a circle next to the appropriate response. Test has two parts, each with a 3-min time limit. Score = number correct. Source: Differential Aptitudes Battery (Bennett, Seashore, & Wesman, 1972).

Perceptual Speed

This is a test of inspection and matching. Subjects are given sets of five drawings of stylized common objects (e.g., spoon, house) that differ in minor details. Subjects must then match sets of probe items to the corresponding comparison objects. Test has one part with a 5-min time limit. Score = number correct − (.20* number wrong). Source: Guilford-Zimmerman Aptitude Survey; Sheridan Psychological Services.

Number Sort

This test requires that subjects choose and mark, from a set of five numbers (6–9 digits in length) either the largest (Part I) or the smallest (Part II) numbers in the sets. Test has two parts with a 1.5-min time limit for each part. Score = number correct − (.20* number wrong). Source: locally developed.

Letter Sets

This is a test of inductive reasoning. Subjects are given items that contain five sets of letters (e.g., NOPQ DEFL ABCD HIJK UVWX) and must choose the set that will not fit the rule defined by the other four sets. Test has two parts with a 7-min time limit for each part. Score = number correct − number wrong. Source: ETS Kit of Factor-Referenced Cognitive Tests; Ekstrom, French, Harman, & Dermen, 1976.

Raven Advanced Progressive Matrices I and II

This is a test of inductive reasoning. Subjects are given an item that contains a figure (with three rows and columns) with the lower right-hand entry cut out, along with eight possible alternative solutions. Subjects choose the solution that correctly completes the figure (across rows and columns). The test has two parts, a brief Part I (5 min) and a longer Part II (40 min). Score = number correct. Source: Raven, Court, & Raven, 1977.

Figure Classification

Test of inductive reasoning. Subjects are given sets of figures comprising two defined groups and then a series of probe items that can be classed into one of the two groups. Subjects respond by writing in the number of the appropriate group. Test has two parts with an 8-min time limit for each part. Score = number correct − (.5* number wrong). Source: ETS Kit of Factor-Referenced Cognitive Tests; Ekstrom et al., 1976.

Analogies

This is a test of analogical reasoning. Items are multiple choice and take the form of A : B :: C : (d_1, d_2, d_3, d_4). Subjects choose the response that correctly completes the analogy. Test has one part with a 30-min time limit. Score = number correct. Source: 60 Miller Analogies Test Practice Items, Bulletin of Information and List of Testing Centers with 60 Practice Items for the MAT, 1970.

Practice Tasks

Nine-Choice RT (Computer Based)

Stimuli were Digits 1 through 9. Responses were made using the same number keys on the computer numeric keypad.

Four-Choice RT (Computer Based)

Stimuli were digits 1, 2, 4, and 5. Responses were made using the same number keys on the computer numeric keypad.

Two-Choice RT (Computer Based)

Stimuli were Digits 1 and 2. Responses were made using the same number keys on the computer numeric keypad.

Simple RT (Computer Based)

Stimulus was the Digit 1. Responses were made using the same number key on the computer numeric keypad.

For all the Choice-RT tasks, each trial consisted of a focus dot for 800 ms, the stimulus presentation, and feedback (RT, average RT, and cumulative accuracy over a block of trials). One block = 25 trials. (Performance was measured as the mean RT in ms for correct responses.) The Choice-RT tasks had stimulus uncertainty and temporal certainty. For the Simple RT task, a random duration focus dot was used to introduce time uncertainty, given the lack of stimulus uncertainty. Thus, the Simple RT task had stimulus certainty and temporal uncertainty. The focus dot was displayed for durations with a boundary of 800 to 1200 ms. Each of the four tasks was administered in a baseline format (two 25-trial blocks) during the first experiment session (to minimize effects of practice-related transfer of training that may have occurred if all practice on each of the tasks preceded initial experience with the other tasks). In subsequent sessions, each task was given in a continuous series of 10 trial blocks. Thus, data were collected on twelve, 25-trial blocks on each task, for a total of 300 trials.

Letter/Number Substitution II

This task is conceptually similar to digit-symbol tests, with the change from symbols to English letters. The top of each page showed a mapping of the letters A, B, C, D, E, F, G, H, and I with the numbers 9, 8, 7, 6, 5, 4, 3, 2, and 1, respectively. A list of randomly ordered letters was given below, with spaces for the subjects to write in the numbers that corresponded to the letters in the mapping. Each page had 11 rows and 25 columns of letters. A single mapping was used throughout the task. Ten parts of the task were administered. Each part was given a time limit of 1.5 min. Score = 90 ÷ (number correct − number wrong). Thus, performance is measured as RT in s, time to complete one item.

Number Comparison

A classic proofreading test. Each part of the task consisted of two 50-item columns of number pairs on one sheet of paper. Subjects were instructed to place a check mark between the numbers that exactly matched. Ten parts of the task were administered. Each part was given a time limit of 1.5 min. Score = 90 ÷ (number correct − number wrong). Thus, performance is measured as RT in s, time to complete one item.

Cancelling A's

This typical perceptual speed task was made up of one-page parts. Each page consisted of 31 rows of 80 columns of randomly generated uppercase English letters. All letters (including the letter A) occurred with equal probability (1/26) on the pages. Subjects were instructed to place a line through each occurrence of the letter A. Ten parts of the task were administered. Each part was given a time limit of 1.5 min. Score = 90 ÷ number correct. Thus, performance is measured as RT in s, time to find one instance of the letter A.

Received August 28, 1989
Revision received December 12, 1989
Accepted February 19, 1990 ■