Swanson, H.L., Cochran, K., & Ewars, C. (1989) Working memory and reading disabilities. *Journal of Abnormal Child Psychology, 17,* 745–746.

Thorndike, E., & Lorge, T. (1944) *The teacher's word book of 30,000 words.* New York: Columbia University, Teachers College.

Turner, M.L., & Engle, R.W. (1989) Is working memory capacity task dependent? *Journal of Memory and Language, 28,* 127–154.

Vanderplas, J.M., & Garvin, E.A. (1959). The associative value of random shapes. *Journal of Experimental Psychology, 57,* 147–154.

Vellutino, F. (1979). *Dyslexia: Theory and research.* Cambridge, MA: MIT Press.

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Individual Difference in Repetition Priming and Its Relationship to Declarative Knowledge Acquisition

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We report two studies that investigated the relationship between repetition-priming effects (i.e., performance facilitation observed in the repetition of a processing event) and declarative knowledge acquisition within repetitive practice paradigms. The first study related repetition priming to paired associate learning, and the second study related repetition priming to the acquisition of computer programming concepts. Differences in working memory, semantic knowledge, and semantic processing speed were also investigated in relation to both repetition priming and learning. In both studies, individual differences in repetition-priming effects uniquely predicted learning differences relative to the other cognitive measures. Results are discussed with respect to the potential importance of individual differences in implicit memory phenomena in some forms of declarative learning.

Repetition priming refers to performance facilitation typically observed when a processing event is repeated. For example, several studies (e.g., Jacoby, 1983; Jacoby & Dallas, 1981; Kirsner, Milech, & Standen, 1983; Masson, 1986) have shown that reading time is reduced for words that have been read previously (repetition delays ranging anywhere from a few minutes to 24 hours). Furthermore, repetition priming such as this does not appear to depend on recall of the original processing events (e.g., Jacoby & Dallas, 1981; Tulving, Schacter, & Stark, 1982).

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The phenomena of repetition priming has been investigated using a variety of cognitive tasks. Substantial and persistent facilitation has been observed for repeated (directly primed) trials in the following tasks: word identification (Feustel, Shiffrin, & Salasoo, 1983; Jacoby, 1983; Jacoby & Dallas, 1981; Jacoby & Hayman, 1987), lexical decision (Forbach, Stanners, & Hochhaus, 1974; Ratcliff, Hockley, & McKoon, 1985; Scarborough, Cortese, & Scarborough, 1977), word-fragment completion (Roediger & Blaxton, 1987; Tulving et al., 1982), word-meaning comparison (Woltz, 1988, 1990a, 1990b), and text processing (Kolers, 1976; Masson, 1986). In general, the findings from these and other studies are consistent in suggesting that performance facilitation from repeating a single processing event is long-lasting, quite specific to surface features of the priming event, and not dependent on recall or recognition of the priming event.

Most repetition-priming research has focused on understanding the nature of facilitation from single repetitions of processing events (cf. Salasoo, Shiffrin, & Feustel, 1985). We postulate, however, that the memory processes responsible for facilitation from a single priming event may be those involved in more complex forms of learning that depend on repetitive practice (for a similar view, see Logan, 1990). One way to test the existence of this relationship is with respect to individual differences. If common memory processes are involved in repetition priming and complex learning from repetitive practice, then individuals who demonstrate larger repetition-priming effects should be more effective learners. In this article, we report two studies that investigated this hypothesized relationship between individual differences in repetition effects from single priming events and differences in learning from multiple practice opportunities. First, we will review previous research findings that suggest the possible link between repetition priming and learning.

Past Research and Theory Linking Repetition Priming and Skill Acquisition

There appear to be obvious similarities between the characteristics of repetition priming and procedural skill acquisition. Both represent performance facilitation from practice, although in one case there is only one practice event. Both repetition priming and procedural skill tend to be relatively long-lasting and resistant to interference compared to most memory phenomena that involve recollection of declarative knowledge (e.g., Hill, 1957; Kolers, 1976; Sloman, Hayman, Ohta, Law, & Tulving, 1988). Both tend to be highly specific. That is, dramatic demonstrations of either skill acquisition or repetition priming are exhibited only when learning and performance conditions are highly consistent (e.g., Ackerman, 1988; Jacoby & Hayman, 1987; Singley & Anderson, 1989; Woltz, 1990a). Finally, performance that demonstrates either repetition priming or procedural skill typically does not depend on effortful or controlled memory processing (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Tulving et al., 1982).

In addition to these shared characteristics, two sources of empirical evidence directly link repetition priming to procedural skill acquisition. The first body of evidence comes from studies comparing amnesic patients and normal adults on learning and memory performance (see Shimamura, 1986, for a review). Despite severe deficits in traditional memory measures such as recall and recognition for new learning, many anterograde amnesic patients do not differ from normals in (a) skill learning and retention (e.g., mirror tracing and pursuit rotor tasks), and (b) repetition priming (e.g., primed word-stem completion and primed fragmented pictures). Squire (1986, 1987) interpreted this as evidence for independent declarative and procedural memory systems that can be differentially affected by neurological impairment. Of interest here is the fact that repetition priming is associated with procedural learning and memory.

The second source of evidence comes from research on individual differences in skill acquisition among normal adults. Woltz (1988) found that differences observed in repetition priming predicted differences in skill learning. Furthermore, the pattern of relationship between repetition priming and skill performance after varying amounts of skill practice was independent of the pattern of relationships for other cognitive measures such as working-memory capacity and semantic knowledge. This evidence suggests that repetition-priming processes may play a role during skill acquisition that is unique vis-à-vis other memory processes.

Past Research Linking Repetition Priming and Declarative Knowledge Acquisition

Although there is considerable evidence linking repetition priming to the acquisition of procedural skill, there is comparatively little to link repetition priming to the acquisition of declarative knowledge (i.e., memory for facts, concepts, and events that can be explicitly described by the learner). Most of the evidence comes from research on amnesic patients, and the results are somewhat mixed.

Some of the evidence from amnesia studies suggests the simple picture that procedural learning functions (including repetition priming) are preserved, but declarative learning functions are lost in cases of anterograde amnesia. That is, new learning is only exhibited with respect to procedural skills (and priming), but not with respect to facts and events (Cohen & Squire, 1980; Squire, 1986, 1987).

Other evidence, however, indicates that the picture is more complex with respect to declarative learning and the types of memory underlying it. For example, amnesic patients have been shown to learn paired associates when word pairs are semantically related, although their performance is typically worse than that of normal subjects (e.g., Winocur & Weiskrantz, 1976). Furthermore, Shimamura and Squire (1984) showed associative learning among amnesics to be equivalent to normal subjects under incidental learning and implicit test procedures. Thus, these studies suggest that despite severe episodic memory impairment, amnesic patients may retain some declarative learning capability involving semantic memory.

The possibility of preserved declarative learning in amnesics has been suggested most clearly in a series of studies by Glisky and colleagues (Glisky & Schacter, 1987, 1988, 1989; Glisky, Schacter, & Tulving, 1986). They found that patients with severe amnesia could learn new declarative and procedural knowledge under the right training conditions, even to the extent that new job skills could be taught for successful employment. Yet, as a function of their amnesia, some of these patients could not even remember that numerous training sessions had occurred (Glisky et al., 1986). Two points regarding the Glisky work are of importance here. First, the learning exhibited by the amnesic patients was not simply procedural. Learning included new terminology with associated meanings, concepts about the procedures learned, as well as the procedures themselves. Second, the learning occurred as a result of repetitive computerized training that provided "vanishing cues." That is, the training was designed to capitalize on preserved repetition-priming effects typically found in amnesic patients.

In sum, the evidence from amnesic patients suggests that repetition priming may be related to some forms of declarative as well as procedural learning. Amnesics who show preserved repetition priming also appear capable of learning new semantic material under the right circumstances, particularly those that appear to capitalize on repetition priming.

Overview of Current Studies

We report two studies that investigated the possible relationship between repetition priming and declarative knowledge acquisition in normal adults. Our approach was to investigate whether individual differences in repetition priming predicted differences in declarative knowledge acquisition under learning conditions that involved repetitive practice. Both studies measured repetition priming using a semantic comparison task (see Woltz, 1988, 1990a, 1990b). In this task, priming is assessed by latency savings on repeated trials that require decisions about whether two words have the same or different meanings (e.g., *moist damp*). Declarative knowledge acquisition was assessed in different ways in the two experiments. The first study assessed knowledge acquisition with a task that provided repetitive practice on fixed sets of paired associates. The second experiment assessed declarative learning during repetitive practice in a sentence-verification task that taught computer programming concepts.

In both experiments, measures of other cognitive abilities were also administered. The purpose of these additional measures was: (a) to investigate the magnitude of correlation between repetition priming and working-memory efficiency, semantic knowledge, and semantic processing speed; and (b) to look at whether repetition priming has any unique explanatory power over and above these cognitive measures in predicting declarative knowledge acquisition.

EXPERIMENT 1

In this experiment, we investigated individual differences in repetition-priming effects at lag intervals ranging from a few seconds to 90 min. We addressed the question of whether individual differences in repetition priming were related to differences in a learning task in which subjects learned new associations (consonant-vowel-consonant, or CVC-word pairs) from extensive practice in verifying correct associations.

Method

Subjects

Subjects were 342 Air Force recruits in their 11th day of basic training at Lackland Air Force Base, TX. Approximately 16% of these subjects were eliminated because performance scores indicated lack of effort (i.e., chance error rates on simple tasks, unrealistically low average response latency on more complex tasks, or failure to complete all tasks). Another 4% of the subjects were eliminated because English was not their primary language. Of the remaining 274 subjects, 210 were male and 64 were female. All subjects were high school graduates and approximately 20% had at least some college work. The age of Air Force recruits ranges from 17 to 27.

Apparatus

All experimental tasks were administered on Zenith Z-248 microcomputers with standard keyboards and EGA color video monitors. Materials were presented on the monitors in 24 × 80 character text mode. Software was written to achieve millisecond timing on response-latency recording.

Procedure

Subjects were tested in groups of 25 to 35, with each subject at an individual testing carrel. Subjects were first given a brief orientation to the experimental session and practice locating keys on the computer keyboard. Then subjects performed four tasks. All task instructions were computer administered, and proctors were available to answer questions. Total time of each session was approximately 3.5 hr.

Subjects completed a choice reaction time task first. Subjects then performed a set sequence of five semantic comparison blocks separated by intervening blocks of an associative learning task. Subjects also performed a working-memory test. Approximately half the sample (n = 129) were randomly assigned to take the working-memory test as the second task, and the remaining subjects (n = 145) took the working-memory test as the last task. Otherwise, the sequence was identical for all subjects. A 2-min rest period followed each associative learning set.

Cognitive Tasks

Choice Reaction Time. Trials presented a string of four asterisks either to the left or right of the center of the computer display. Subjects pressed the D key with the left hand if the symbols were on the left and the L key with the right hand if the symbols were on the right. Latency feedback was provided after correct responses for 1 s. The word WRONG and a low tone was presented for 2 s after incorrect responses. Intertrial time following feedback was 1 s. Two blocks of 32 trials were presented after 10 initial practice trials. After each block, number correct and average response times were displayed.

Repeated Semantic Comparison. Each trial consisted of two words presented in the center of the computer display, one on top of the other separated by approximately 1 cm. Each trial was preceded by an attention cue (one asterisk) presented for 1,000 ms followed by a blank screen for 500 ms. The two words were then presented and remained on the screen until the subject responded by pressing either an L key (for like) or a D key (for different), depending on whether the subject judged the words to be synonyms or unrelated. Subjects were instructed to respond as quickly as possible without sacrificing accuracy.

Response feedback was designed to encourage both response speed and accuracy. An individual's trial response latency was presented for 1,000 ms following correct responses. The word WRONG, a low tone, and the message, BE MORE CAREFUL, followed errors for 4,000 ms. A blank screen followed all feedback frames for 500 ms. After each set of 72 trials, subjects were presented summary feedback of percent correct and median latency, and they were reminded to respond as quickly as possible without making errors.

Subjects performed an initial block of 288 semantic comparison trials (an additional 20 warm-up trials preceded the 288 but were not considered part of the experimental design). One third of Block 1 trials were repeated at relatively short lags. Three orthogonal factors defined the repetitions within Block 1: (a) Positive- versus Negative Match on first exposure trials (e.g., MOIST DAMP vs. MOIST BLUE); (b) Same versus Different Match on second exposure relative to first exposure (e.g., MOIST BLUE repeated as MOIST BLUE vs.MOIST DAMP); and (c) Repetition Lag of second exposure after first exposure (where second exposure was 1, 2, or 8 trials later). A complete representation of the repeated trial design was achieved within every set of 36 trials.

Repetition lags in Block 1 were accomplished in the following manner. The

288 trials were presented as four sets of 72 trials. Each set of 72 trials contained eight 9-trial sequences. The 1st trial in each 9-trial sequence was a Lag 8 first exposure. The next 7 trials represented the first and second exposures of Lags 1 and 2 in a randomly determined order for each 9-trial sequence of each subject. A nonrepeated filler trial always intervened between the first and second exposure of Lag 2 trials, and 2 additional filler trials were randomly assigned (for each sequence of each subject) to potential filler slots before, between, or after Lag 1 and 2 trials. The 9th trial of each 9-trial sequence was always a Lag 8 second exposure.

Blocks 2 to 5 differed in structure from Block 1. Each of these blocks began with 10 warm-up trials followed by 72 trials that were equally divided among three levels of previous exposure. One third of the nonpractice trials in each block had not been presented previously (first exposures); one third had been presented once in Block 1 as fillers (second exposures); and one third had been presented twice in Block 1 as repetitions (third exposures). First-exposure trials were balanced for positive and negative match within each block. Second- and third-exposure trials were always exact repetitions of Block 1 trials, and were balanced within block for match type and order of Block 1 presentation. That is, each of Blocks 2 to 5 contained (a) six fillers (three positive and three negative) from each quarter of Block 1, and (b) six repeated trials (one positive and one negative of each repetition lag) from each quarter of Block 1. Third-exposure trials always presented an exact repetition of the first-exposure trial from Block 1, even if the second-exposure trial in Block 1 was converted to the opposite match type (i.e., if MOIST = DAMP? was repeated as MOIST = BLUE? in Block 1, the third exposure would always be MOIST = DAMP?).

There were 288 stimulus sets (word triplets) used for the semantic comparison trials. Each stimulus set consisted of a stem word, a synonym of the stem, and a word semantically unrelated to the stem (e.g., MOIST, DAMP, BLUE). Stimulus sets were randomly assigned to design cell and trial block for each subject. There were an additional 60 stimulus sets of word triplets randomly assigned for each subject to warm-up trial conditions.

CVC-Word Look-Up. Subjects learned six unique CVC-word pairs in each of four learning trial sets. Each trial within a given set presented: (a) the six CVC-word pairs across the top of the computer display (CVCs were directly above the associated words across the top two rows of the 24 × 80 character display space); and (b) a probe at the bottom of the display (e.g., GUK = coat?). Although the CVC-word pairing remained constant within a set for each subject, the order of the pairs at the top of the display was randomized for each trial. Subjects responded by pressing the L key (for like) or the D key (for different) depending on whether the probe at the bottom matched any pair at the top of the display. Four fixed sets of six CVC-word associations were used as stimuli. The assignment of stimulus set to trial set was random for each subject.

Subjects were instructed to respond as quickly as possible without making errors. On the initial trials in each set, subjects had to search visually for the correct responses to the probes. The random ordering of CVC-word pairs at the top of the display was implemented to maximize the time required for this search process. With practice however, subjects could presumably learn the associations and thereby eliminate the need for time-consuming visual searches. Subjects were explicitly told that learning to recall the associations rather than look up for them would greatly improve their performance. However, subjects were never allowed extended time to memorize the associations. Response time was limited to 5 s per trial, after which the display was erased and the message, TOO MUCH TIME, was presented for 3 s before the next trial. The task was intended to represent the acquisition of associations through brief repetitive practice episodes that did not allow for elaborative encoding of the associations.

Within each of the four sets, trials were presented in 16 blocks of 24 items. Each block consisted of four replications of each stimulus set presented twice as positive and twice as negative trials. Each negative trial probe consisted of a CVC and a randomly selected word from the set of five incorrect alternatives within the stimulus set. Trial order was randomized for each subject with the constraint that adjacent trials could not contain common CVCs or words. A practice set was provided prior to the four learning sets. The practice set was identical in structure to the valid sets except there were only 6 blocks of 24 trials.

No feedback was given after a trial unless the response was incorrect. Incorrect responses were followed for 3 s by a low tone and the message, BE MORE CAREFUL. Percent correct and average latency were displayed at the end of each trial block for 5 s. Before the beginning of each block, subjects were reminded to respond as fast as possible without making errors and to try to learn the word pairs so they would not have to look up.

ABC Assignment. This task was used previously as a measure of working-memory capacity (Christal, 1985; Kyllonen & Christal, 1990). Each of 15 trials consisted of three study and three response frames. The three study frames were presented first and contained the letters A, B, or C and an arithmetic expression assigned to each (e.g., C = B/4; A = 23; B = 8 × 2). As in the example, some expressions (C = B/4) could not be solved until later frames were presented. Subjects could view each study frame for as long as needed but they could not return to previous frames. Following the study frames, the three response frames probed for the answers to each letter (e.g., A = ?; C = ?; B = ?). Subjects entered their answers using the number keys at the top row of the keyboard.

Results

Semantic Comparison Repetition Effects

Error rates were generally low over all semantic comparison trial conditions, M = 5.83% (SD = 2.71). Moreover, error rate was positively correlated with response latency across the 56 trial conditions (r = .32) and across individuals (r = .13). Thus, faster latency was associated with fewer errors.

The analyses of mean repetition effects for both accuracy and latency are reported elsewhere (Woltz & Shute, 1993). Short repetition lags (0–7 intervening trials) produced mean latency savings of 200 to 300 ms. Lags of 30 to 90 min produced comparatively smaller priming effects, but they were still generally greater than 100 ms.

For the analysis of individual differences, latency facilitation in repeated trials was expressed by least squares regression residuals rather than difference scores. Second-exposure latency was regressed on first-exposure latency within trial type and repetition lag. A negative residual reflected someone faster on second-exposure trials than predicted by their first exposure trial latency, whereas a positive residual reflected someone slower on second-exposure trials than predicted by their first-exposure latency.

Internal consistency reliability was estimated by correlating residual scores computed separately for odd and even trials and adjusting for test length with the Spearman-Brown formula. Immediate priming effects (Lags 1, 2, and 8 repetitions from Block 1 combined) had an estimated internal consistency reliability of $r_{xx'}$ = .75 and persistent priming effects (Block 2–5 repetitions combined) had an estimated internal consistency reliability of $r_{xx'}$ = .80. These estimates suggest that measurable individual differences exist in repetition at a wide range of delay intervals.[1]

Correlations among immediate and persistent priming scores and the working-memory and choice reaction time tasks are presented in Table 1. Despite moderately high internal consistency reliability estimates, immediate priming had only modest correlations with persistent priming (r = .46). This suggested that level of immediate facilitation and decay of that facilitation may represent partially independent processes (see Woltz, 1990b, for further evidence of this independence). Note, also, that correlations of repetition priming with working memory and choice reaction time were generally low.

Relation of Repetition Priming to Learning

Subjects showed evidence of systematic and consistent learning across the four learning-trial sets. Figure 1 shows latency means by set and trial block for the learning task. Note that Set 1 mean latency was consistently longer than that for Sets 2 to 4. This difference probably represents task familiarization unique to Set 1. In all sets, mean response latency was less than half of the initial mean latency within the first 8 trial blocks. In contrast, mean latency reduction was minimal in the last 8 trial blocks. These data suggest that the majority of associative learning and corresponding reduced need to search visually for correct associates at the top of the display occurred in the initial trial blocks.

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[1] The number of trials used to compute immediate priming was one third that used to compute persistent priming. The immediate priming measure would be expected to have higher reliability than the persistent priming measure if they were of equal lengths.

TABLE 1
Intercorrelations and Internal Consistency Reliability Estimates for Immediate and Persistent Priming, Working Memory, and Choice Reaction Time Measures

	1	2	3	4
1. Immediate Priming (<30 s)	(.75)			
2. Persistent Priming (30–90 min)	.46	(.80)		
3 ABC Assignment (Errors)	.19	.15	(.92)	
4. Choice Reaction Time	.27	.11	.03	(.92)

Note. $N = 274$. Diagonal values (in parentheses) represent split-half reliability estimates. Correlations of $r \geqq .14$ are significantly different from zero at $p < .01$.

Mean error rate was 6.61% ($SD = 3.30$) over all sets and trial blocks. Internal consistency (split-half) reliability for trial-block latency ranged from $r_{xx'} = .88$ to $r_{xx'} = .97$, with a trend of increasing internal consistency over trial blocks.

Figure 2 shows the pattern of correlations for repetition priming, working memory, and choice reaction time with learning-task latency by trial block for Sets 1 to 4 combined. Correlations for immediate and long-term priming did not differ, so these variables were combined in a composite. Correlations were transformed to Fisher *z* scores for plotting and trend analysis.

As seen in Figure 2, repetition priming had a different pattern of correlation with the learning task than either working memory or choice reaction time. Repetition priming had its highest correlations ($r = .37$) with early trial-block latency. These correlations declined slightly over trials, but remained relatively high throughout the task. The negative liner trend over blocks of *z*-transformed correlations was significant, $R^2 = .30$, $F(1, 14) = 6.03$, $p < .05$. In contrast, the working-memory test had a low correlation with the earliest trials ($r = .10$). This correlation gradually increased through the first half of the trials (to $r = .28$) and remained constant or decreased slightly thereafter. The linear and quadratic trends over trial blocks of *z*-transformed working-memory correlations were significant, $R^2 = .80$, $F(2, 13) = 25.79$, $p < .001$. Finally, correlations of choice reaction-time latency with learning-task latency were comparatively low throughout ($r = .12$ to $r = .20$). However, the positive trend over learning-trial blocks seen in Figure 2 was significant, $R^2 = .32$, $F(1, 14) = 6.67$, $p < .05$.

Multiple regression analyses were also performed to test whether the three cognitive measures in this study made unique or overlapping contributions in predicting learning-task performance. The 16 learning-task median response latency variables were collapsed into four variables representing four blocks of performance each. These variables were each regressed on repetition priming, working memory, and choice reaction time. Repetition priming and working memory made unique contributions in each of the four quarters of task performance ($p < .05$). Choice reaction time made a unique contribution in only the last quarter ($p < .05$). Thus, repetition priming made unique contributions to working memory and choice reaction time in explaining performance at all phases of learning in this task.

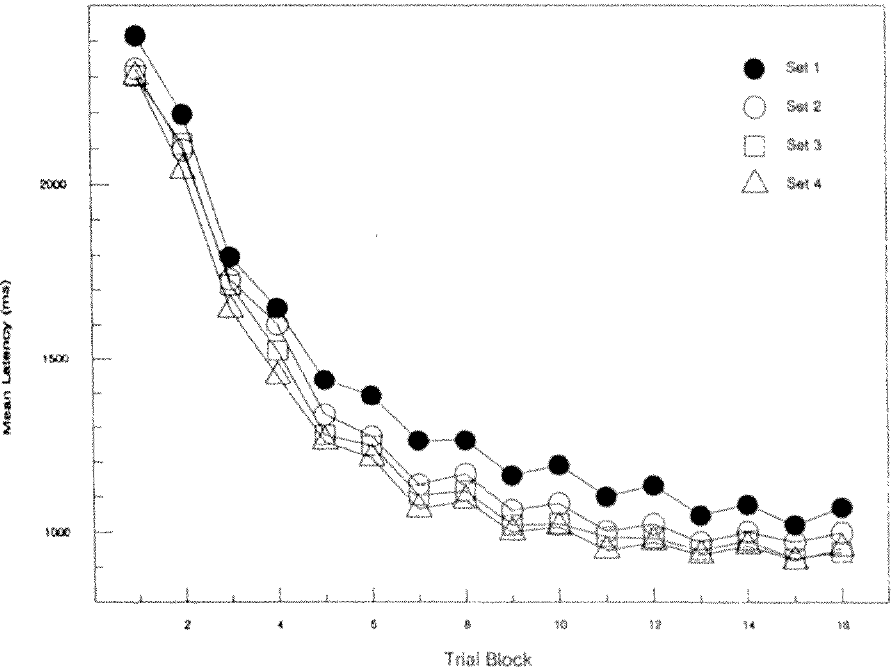

Figure 1. Experiment 1 mean latency by trial block for Sets 1 to 4 of the associative learning task.

Discussion

The distinctive patterns of correlation across learning blocks for repetition priming in contrast to working memory and choice reaction time suggested the involvement of different cognitive processes at different stages of the learning. Despite increasing reliability of learning performance across trial blocks, the repetition priming had slightly declining correlations across blocks. This was in contrast to both working-memory and choice reaction time measures, which had increasing correlations across learning blocks.

These correlations suggested a unique involvement of repetition priming in the formation of new associations from repeated practice in verifying instances. Mean data in Figure 1 suggested that most subjects' responses reflected recall

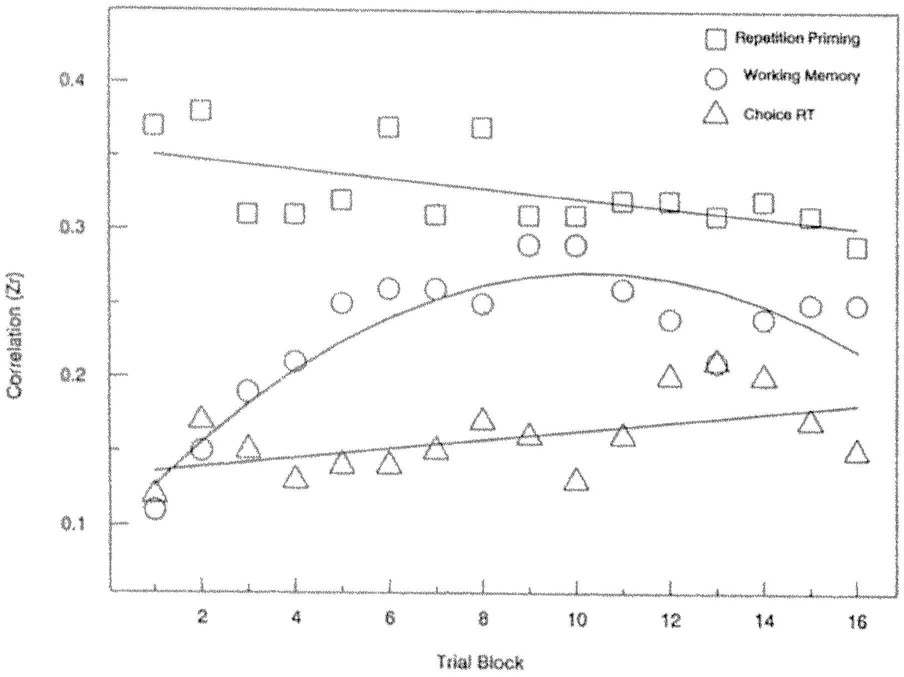

Figure 2. Experiment 1 z-transformed correlations of repetition priming, working memory, and choice reaction time with associative learning performance by trial block.

rather than visual search only after the first 6 to 8 trial blocks. The repetition-priming variable had its highest correlations with the first 8 blocks during which most associative learning presumably took place. In contrast, working memory did not correlate substantially with this task until about the 6th block. In other words, subjects with greater repetition priming showed better associative learning performance from the beginning, where each exposure presumably resulted in some build-up of associative strength. Subjects with greater working-memory capacity did not show substantially better performance until associations presumably had been well formed, and performance depended on efficient retrieval and comparison processes.

The fact that working memory did not initially predict associative learning performance was contrary to other findings of working memory's role in early stages of learning. Initial stages of declarative learning are thought to place heavy demands on working memory (Anderson, 1983, 1987; Kyllonen & Woltz, 1989; Woltz, 1988) and general problem-solving processes (Ackerman, 1988, 1990). The contrary pattern of correlations with working memory found here is probably due to the unique nature of this learning task. The learning task was designed to minimize effortful, elaborative processing of new declarative knowledge, and instead, to maximize learning from repetition of relatively simple processing. During the initial learning trials, subjects were forced to do nothing more than search the display for the appropriate information and respond accordingly. Such visual searching should not place heavy demands on working memory in the way other learning tasks do when large amounts of new declarative knowledge must be maintained in temporary storage.

Despite the relatively low correlations of choice reaction time to learning performance, the pattern of increasing magnitude was important. First, the pattern was consistent with theory and data reported by Ackerman (1988, 1990). Ackerman as well as Fleishman (1972) argued that after sufficient practice, most tasks' performance depends more on perceptual and motor components, and correlations with psychomotor tasks should increase. Second, the increasing correlations of choice reaction time with learning performance eliminated an alternative interpretation for the repetition-priming correlation pattern. That is, the decreasing correlations of repetition priming (a latency-based measure) with learning-task latency could have reflected the fact that processing-speed differences are most important early in the task when subjects must visually search and respond. Because choice reaction time showed the opposite pattern, this interpretation seems implausible.

In sum, these data demonstrate the existence of systematic individual differences in repetition-priming effects. Differences were reliable across different item sets of the semantic comparison task and they predicted differences in associative learning in a task that emphasized repetitive practice.

EXPERIMENT 2

In this experiment we addressed the same questions as Experiment 1 with several additions. First, we measured repetition-priming effects with greater lag intervals, ranging up to 8 days. In Experiment 1, correlations between priming at short and long (30–90 min) lag intervals had only modest correlations. This suggested that immediate and persistent priming effects may reflect somewhat different processes, or that differences in priming decay may be partially independent of differences in initial facilitation. In Experiment 2, we explored this question by comparing correlations of immediate and 8-day repetition effects with a variety of cognitive measures.

A second difference from Experiment 1 was that we included a wider variety of cognitive measures for correlation with repetition-priming effects and declarative learning measures. We measured three categories of processing abilities that presumably reflect different aspects of declarative memory performance. We administered several measures each of (a) working-memory efficiency, (b) semantic processing speed, and (c) semantic knowledge.

The final new feature of Experiment 2 was the inclusion of a different learning task for correlation with the repetition-priming effects. The learning task in Experiment 1 was designed to stimulate learning through repetitive practice with minimal use of effortful and elaborative learning processes. We investigated correlations with this learning task first because we thought differences in repetition effects would be most consequential in this type of learning. The question we addressed in Experiment 2, however, was whether differences in repetition priming also predicted differences in learning in a more traditional learning paradigm and with more meaningful learning materials. In this experiment, subjects learned 10 concepts from the domains of mathematics and computer programming. Subjects verified complex statements about the concepts until they could do so without error. Unlike the learning task in Experiment 1, this task emphasized accuracy rather than speed, and there were no study-time restrictions. Consequently, this task was thought to represent complex learning that relied more heavily on effortful memory processes better. However, as in Experiment 1, the learning task presumably involved semantic knowledge that was acquired over multiple, rather than single, learning episodes.

Method

Subjects

The subjects in this study consisted of 250 male and female students participating in an 8-day study on acquisition of Pascal programming skills from a Pascal intelligent tutoring system (ITS; see Shute, 1991). Subjects were recruited and selected from San Antonio, TX colleges and technical schools to match demographic and general ability characteristics of the Air Force enlisted population. Twenty-five percent of the total sample was eliminated from analyses presented here because they did not complete all experimental tasks. Approximately 13% of the remaining subjects were eliminated because performance scores indicated lack of effort (i.e., chance error rates or unrealistically long average response latencies). Of the remaining 163 subjects, 134 were male and 29 were female. All subjects were high school graduates with a mean age of 22.4 (*SD* = 3.23). All subjects were paid for their participation in 40 hours of testing and instruction.

Apparatus

The cognitive ability tasks were administered on Zenith 248 microcomputers with standard keyboards and EGA color video monitors. Materials were presented on the monitors in 24 × 80 character text mode. Software was written to achieve millisecond timing on response-latency recording.

The learning task was administered on Xerox 1186 artificial intelligence workstations with standard keyboards and high-resolution (1024 × 80) monochromatic displays on 19-in. (48.26-cm) monitors. Software was written in Interlisp-D and LOOPS.

Procedure

Subjects participated in the study in groups of 15 to 25. On the morning of Day 1, subjects were given a brief orientation to the entire study. They then took 6 hours of computer-administered cognitive ability tasks, with short breaks between tasks and a 1-hour break at noon. Block 1 of the semantic comparison task from Experiment 1 was administered at this time. Different subjects received different orders of the cognitive tasks, but the semantic comparison task was administered within the first 3 hours of the morning session for all subjects.

Day 2 for each subject began with orientation to the AI workstations. Next, subjects performed the Programming Concepts learning task. Following this, subjects received 4 days of instruction in Pascal programming from an ITS. Data from the ITS training are reported elsewhere (Shute, 1991).

On the morning of the 7th weekday of each subject's participation, those who had completed the Pascal tutor were administered alternate forms of the computer-administered cognitive ability tasks. Blocks 2 to 5 of the semantic comparison task from Experiment 1 were administered within this battery. Again, different subjects received different orders of the tasks, but all subjects received the semantic comparison blocks within the first 3 hours. Because the semantic comparison task was administered on the 1st and 7th day of a subject's participation, and a weekend interrupted every subject's 7 days, 8 days always intervened between first and second administrations of the repeated semantic comparison task.

Cognitive Tasks

A total of 25 computer-administered cognitive ability measures and 10 paper-and-pencil subtests of the Armed Services Vocational Aptitude Battery (ASVAB) were administered to the subjects in this study. We used data from only 11 of these tasks in our analyses. First, we were primarily interested in three ability constructs in relation to repetition priming and declarative knowledge acquisition: semantic knowledge, working-memory efficiency, and semantic processing speed. Some of the cognitive measures and ASVAB subtests represented other ability or knowledge constructs. Second, to preserve the maximum sample size, we eliminated measures that had substantial numbers of missing cases on the second administration (Day 8). This left us with four measures of semantic knowledge (KNO), four measures of working-memory efficiency (WM), and three measures of semantic processing speed (PS). All but two of the cognitive ability measures were administered in separate forms (A and B) on Day 1 and Day 8. Two of the semantic knowledge measures were taken from the ASVAB, which was only administered once on Day 2.

Reading Span (KNO and WM). This task was patterned after the working-memory paradigm developed by Daneman and Carpenter (1980). Subjects were presented a list of general knowledge statements to which they immediately responded TRUE or FALSE (e.g., A BAROMETER IS AN INSTRUMENT USED TO RECORD EARTHQUAKE VIBRATIONS.). Half of the items were true and half were false. After reading and responding to a set of sentences (2–6), they were asked to recall the last word in each sentence (e.g., VIBRATIONS, from the preceding example). To respond, subjects typed in the first two letters of each word in the correct order of appearance. There were 31 trials in each form. Accuracy from the sentence-verification probes was used as a semantic knowledge measure, and word-recall accuracy was used as a measure of working memory.

General Knowledge Survey (KNO). Each form of this task consisted of 50 factual questions for free recall (e.g., WHAT IS THE PROCESS BY WHICH PLANTS MAKE ENERGY FROM SUNLIGHT?). Subjects responded by typing the first two letters of the answer (e.g., PH for photosynthesis). Questions were obtained from the Nelson and Narens (1980) general knowledge questionnaire. Performance accuracy was used as a measure of semantic knowledge.

ASVAB General Science (KNO). This test contained 25 multiple choice questions on facts from the physical and biological sciences (Department of Defense, 1984). There was an 11-min time limit. Performance accuracy was used as a measure of semantic knowledge.

ASVAB Word Knowledge (KNO). This was a 35-item multiple choice vocabulary test (Department of Defense, 1984). There was an 11-min time limit. Performance accuracy was used as a measure of semantic knowledge.

ABCD Order (WM). This task had been previously used as a measure of working-memory efficiency (Christal, 1985; Kyllonen & Christal, 1990). Each trial of this task consisted of three sequential statements describing the correct ordering of the letters A, B, C, and D. For example, the three study frames of a trial might be: C FOLLOWS D, B DOES NOT PRECEDE A, AND SET 1 IS FOLLOWED BY SET 2 (SET 1 refers to A and B, and SET 2 refers to C and D). Subjects were allowed to study each frame for as long as needed, but they could not return to previous frames. After the three study frames, an eight-alternative multiple choice response frame appeared. Subjects pressed a number key corresponding to their answer (ABDC would be the correct answer to the example). There were 15 trials on each form. Performance accuracy was used as a measure of working-memory efficiency.

ABC Assignment (WM). This task was the same as described in Experiment 1. There were 15 trials per form. Performance accuracy was used as a measure of working-memory efficiency.

Mental Math (WM). Subjects performing this task had to calculate a subtraction or division problem mentally (e.g., 207 ÷ 9; 59 − 37). A problem appeared on the screen for 2 s, preceded by a warning asterisk, then disappeared. When subjects were ready to answer the question, they had 4 s to choose among five alternatives. There were 20 items on each form of this test. Performance accuracy was used as a measure of working-memory efficiency.

Semantic Relation (PS). Subjects had to determine whether or not simple sentences were true or false (e.g., THEFT IS A CRIME). They pressed the D (different) key for false items and the L (like) key for true items. There were 72 items on each form of this test. Median latency for all trials was used as a measure of semantic processing speed.

Number Comparison (PS). Subjects were presented with two single-digit numbers on separate sides of the computer screen. They were to determine which of the two numbers was larger. If the one on the right side was larger, they chose L (on the right side of the keyboard); if the one on the left side of the screen was larger, they chose D (on the left side of the keyboard) as the correct response. Each set of numbers was preceded by a warning asterisk and a 1-s delay. There were 36 items on each form of this test. Median latency for all trials was used as a measure of semantic processing speed.

Number Fact Retrieval (PS). Four sets of simple arithmetic problems were presented in this task. Each set contained only one type of problem (i.e., addition, subtraction, multiplication or division). Each problem (e.g., 9 × 3 = 27; 6 + 7 = 14) was preceded by a warning asterisk. Subjects had to determine quickly whether or not the problem was correct (L) or incorrect (D). There were 50 items on each form of this test. Median latency for all trials was used as a measure of semantic processing speed.

Semantic Comparison. This was identical to the repetition priming task used in Experiment 1. Block 1 was administered on Day 1 and Blocks 2 to 5 were administered contiguously on Day 8.

Programming Concepts Instruction. This task provided instruction for concepts of computer programming as well as some basic mathematics concepts. The 10 concepts were *integer, real number, string, data, sum, product, constant, variable, expression,* and *value assignment.* This task served as a pretutor in the larger study of learning Pascal programming from an ITS (see Shute, 1991).

Prior to administration of the Programming Concepts task, all subjects were administered a paper-and-pencil pretest to measure related, incoming knowledge. Twelve questions corresponding to each of the 10 concepts yielded a total of 120 items. These items included examples and definitions, and half were true and half were false. For instance, they had to indicate whether a variety of examples and statements about the concept *real number* were true or false (e.g., 0.32145; −456.0; thirty-seven; 999-88-7654; 3/0; A *real number* can have only one number after the decimal point; A *real number* can be positive or negative).

Subjects then received the Programming Concepts learning task starting with an initial definition of each concept, for example,

> STRING: A word or phrase that starts and ends with single quotes. A string can also consist of numbers, symbols, or different combinations of these things. As long as they are inside of single quotes, the computer will treat them literally (i.e., without trying to evaluate them).

After a definition, subjects received eight questions relevant to the concept. For example, subjects would be asked if the following was a string ' . . . *Is this a string???*.' After responding yes or no with a mouse, subjects received feedback that reiterated the definition. After all 10 concepts had been presented with eight questions each, the instruction cycled through the concepts again with new questions. There were a total of 48 unique questions for each concept. No subject required more than six sets of eight questions to learn each concept to criterion. Concepts dropped out only after two successive blocks of 100% accuracy on the eight questions.

During instruction, subjects had the option to view examples of any concept. If a subject elected to see examples, three positive and three negative examples appeared on the screen. Positive examples of integer included −1 and 44, whereas negative examples included −0.1 and 888.888.

Results

Semantic Comparison Repetition Effects

There were significant repetition effects at both immediate (< 30 s) and 8-day repetition lags. Repetition priming averaged 158 ms ($SD = 83$) across all trial conditions at lags of less than 30 s. Priming averaged 49 ms ($SD = 64$) across all trial conditions after a lag of 8 days. The mean priming data and analyses of different memory-decay models are reported in more detail elsewhere (Woltz & Shute, 1993).

As in Experiment 1, individuals' latency savings from repeated trials were expressed as least squares regression residuals. Residuals representing immediate priming (Lags 1, 2, and 8 in Block 1) had a split-half reliability estimate of $r_{xx'} = .77$ and residual representing persistent priming (Blocks 2–5 from Day 8 combined) had a split-half reliability estimate of $r_{xx'} = .75$. These relatively high internal consistency reliability estimates suggested that measurable individual differences existed in priming even after 8 days.

Despite these moderately high internal consistency reliability estimates for both immediate and persistent repetition priming, there was a low correlation between the two measures ($r = .14$, $p > .05$). This correlation estimate differed significantly ($z = 3.57$, $p < .01$) from the same estimate computed in Experiment 1 ($r = .46$), where persistent priming was defined by lags of 30 to 90 min rather than 8 days. This is consistent with the suggestion from Experiment 1 that level of immediate facilitation and degree of subsequent decay may represent partially independent processes.

Measures of Semantic Knowledge, Working Memory, and Semantic Processing Speed

Table 2 contains mean performance data for the knowledge, working-memory, and processing-speed tasks. The means are listed separately for the two administrations of each task (recall that the ASVAB subtests were only administered once.) Also presented in Table 2 are correlations between test administrations. These correlations represent alternate forms' reliability estimates with an 8-day delay (no correction for test length). As seen in Table 2, most of the cognitive measures were reasonably stable over both item sets and a 1-week time interval.

The correlations among the 11 cognitive measures are shown in Table 3. The

TABLE 2

Means, Standard Deviations, and Alternate Form Correlations for Semantic Knowledge, Working Memory, and Processing Speed Measures

	Form A		Form B		
Cognitive Task	*M*	(*SD*)	*M*	(*SD*)	r_{AB}
Semantic Knowledge					
Fact Verification	32.9	(13.9)	31.8	(11.9)	.51
Knowledge Survey	32.0	(16.5)	38.3	(22.1)	.77
General Science (ASVAB)	44.0	(7.6)	—	—	.86[a]
Word Knowledge (ASVAB)	44.3	(4.9)	—	—	.92[a]
Working Memory					
ABCD Order	55.5	(25.7)	55.7	(29.4)	.67
Reading-Span Recall	32.9	(20.5)	33.2	(27.8)	.53
ABC Assignment	45.9	(24.9)	55.7	(29.5)	.67
Mental Math	46.6	(24.8)	43.5	(27.4)	.65
Semantic Processing Speed					
Semantic Relations	1761	(378)	1484	(436)	.65
Number Size Comparison	516	(82)	511	(128)	.58
Number Fact Retrieval	1277	(363)	1039	(338)	.59

Note. $N = 163$. Semantic knowledge and working-memory variables are percent-error scores; semantic processing speed variables are latency scores (ms).

[a] The correlations for ASVAB scores are internal consistency reliability estimates (Department of Defense, 1984).

TABLE 3
Intercorrelations of Semantic Knowledge, Working Memory, and Semantic Processing Speed Measures

	1	2	3	4	5	6	7	8	9	10	11
1. Fact Verification	—										
2. General Knowledge	69	—									
3. General Science	71	65	—								
4. Word Knowledge	61	66	64	—							
5. ABCD Order	52	50	52	44	—						
6. Reading Span	33	32	25	29	35	—					
7. ABC Assignment	47	47	46	40	57	58	—				
8. Mental Math	35	43	36	30	55	31	67	—			
9. Semantic Relations	17	26	28	32	23	18	17	09	—		
10. Number Comparison	14	25	22	22	21	27	40	27	56	—	
11 Number Retrieval	15	28	23	19	17	20	38	35	55	63	—

Note N = 163. The semantic knowledge variables (1–4) and the working-memory variables (5–8) represent performance errors The semantic processing-speed variables represent response latencies. Correlations of $r \geqq .19$ are significantly different from zero at $p < .01$.

pattern of these correlations generally supports the a-priori distinction between knowledge, working-memory, and processing-speed measures. A principal axis factor analysis of these variables produced a three-factor solution that accounted for 62% of the variance. The three factors corresponded to the knowledge, working-memory, and processing-speed constructs.

Correlations of Knowledge, Working Memory, and Processing Speed With Repetition Priming

We estimated correlations between the three cognitive ability constructs and repetition priming by first computing factor scores for all subjects with respect to each ability construct. In creating these scores, separate principal components analyses were conducted on the variables designed to represent each construct. The different administrations of each test (except ASVAB tests) were treated as separate variables. The first principal component of the six semantic knowledge variables accounted for 67% of their variance. The first principal component of the eight working-memory variables accounted for 52% of their variance. Finally, the first principal component of the six semantic processing-speed variables accounted for 58% of their variance. The factor scores from these analyses were then used in subsequent correlations with repetition priming and learning measures.

Table 4 presents the correlations of immediate and persistent repetition priming with the semantic knowledge, working memory, and semantic processing speed measures. The pattern of correlations shown here suggests that working memory and semantic processing speed may be more highly related to immediate priming, whereas semantic knowledge may be more related to the persistence of priming. The differences between immediate and persistent priming correlations shown in Table 4 were not statistically significant, however, this pattern was consistent with results by Woltz (1990b) showing that the decay of priming was related to knowledge, but not working-memory, measures.

TABLE 4
Correlations of Immediate and Persistent Repetition Priming With Semantic Knowledge, Working Memory, and Semantic Processing Speed Factors

	Correlation (r)	
Factor	Immediate Priming (<30 s)	Persistent Priming (8 days)
Semantic Knowledge	.15	.25
Working Memory	.25	.12
Semantic Processing Speed	.37	.29

Note. N = 163. Correlations of ≧ .19 were significantly different from zero at $p < .01$.

Relation of Repetition Effects and Other Cognitive Measures to Learning Efficiency

Prior knowledge of the 10 programming concepts was measured by the paper-and-pencil pretest. Mean errors on the pretest were M = 32.0 (SD = 11.0). Total time to complete the learning task was used to represent learning efficiency in the Programming Concepts task because of the drop-out procedure employed. Completion time ranged from 22 to 158 min (M = 86.6, SD = 34.0), and it closely approximated a normal distribution.

Correlations between programming concepts performance and repetition priming, semantic knowledge, working memory, and semantic processing speed are shown in Table 5. The programming concepts variables shown in Table 5 include pretest errors, learning time, and adjusted learning time. Adjusted learning time was learning time adjusted for initial knowledge differences by removing pretest variance using linear regression. Pretest errors correlated r = .57 with learning time.

As seen in Table 5, persistent repetition priming had low correlations with pretest errors, learning time, and adjusted learning time. In contrast, immediate repetition priming had a low correlation with pretest errors, but moderate correlations with learning time and adjusted learning time (r = .35 and r = .32, respectively). Thus, immediate, but not persistent, priming appeared to be related to learning in the programming concepts task.

Semantic knowledge, working memory, and semantic processing speed measures had significant correlations with all three learning-task variables. Pretest scores for programming concepts were better predicted by semantic knowledge

TABLE 5
Correlations of Learning Measures From Programming Instruction With Immediate and Persistent Repetition Priming, Semantic Knowledge, Working Memory, and Semantic Processing Speed

	Learning Measure		
Covariate	Pretest Errors	Learning Time	Adjusted Learning Time
Immediate Repetition Priming	.14	.35	.32
Persistent Repetition Priming	.13	.15	.09
Semantic Knowledge (Errors)	.54	.51	.25
Working Memory (Errors)	.46	.54	.34
Semantic Processing Speed	.29	.43	.32

Note. $N = 163$. Adjusted learning time scores were residuals from least squares regression of learning time on pretest errors. Correlations of $r \geqq .19$ were reliably different from zero at $p < .01$.

($r = .54$) and working memory ($r = .46$) than by semantic processing speed ($r = .29$). Learning time and adjusted learning time were predicted equivalently by semantic knowledge, working memory, and processing speed. However, adjusting learning time for prior knowledge resulted in a substantial loss of predictive power for all three of these variables. This was in contrast to the relationship of immediate repetition priming to learning. Immediate priming had little relationship to prior knowledge and correlated almost as highly with adjusted learning time ($r = .32$) as it did with learning time ($r = .35$).

A multiple regression was performed to test whether the relationship of repetition priming to learning was unique or overlapping with covariation among the other cognitive factors and learning time. Learning time was regressed on pretest scores, immediate repetition priming, semantic knowledge, verbal working memory, and semantic processing speed. Approximately half of the learning time variance was accounted for ($R^2 = .51$), and the variables with significant unique contributions were pretest, $F(1, 157) = 19.79$, $p < .01$, working memory, $F(1, 157) = 11.79$, $p < .01$, semantic processing speed, $F(1, 157) = 7.29$, $p < .01$, immediate repetition priming, $F(1, 157) = 6.81$, $p < .01$, and semantic knowledge, $F(1, 157) = 4.06$, $p < .05$. Thus, some individual differences in learning time were uniquely accounted for by repetition priming.

Discussion

Correlations of priming measures with the learning of programming concepts, as well as with semantic knowledge, working memory, and semantic processing speed measures, all suggested meaningful individual differences in both immediate and persistent repetition priming. The correlations between repetition priming and learning performance were generally consistent with findings from Experiment 1. However, two differences are worth noting. First, in Experiment 1, immediate and persistent priming had equivalent correlations to learning. In Experiment 2, only immediate priming showed a relationship to learning performance. One explanation for this finding is that persistent priming measures represent two aspects of priming: immediate priming strength and priming decay. If only immediate priming strength underlies knowledge acquisition, then longer repetition lags (e.g., 8 days) would reduce the relationship of priming to learning.

A second difference in the two experiments was in the learning tasks. The Experiment 1 learning task was purposefully designed to represent passive associative learning through repeated exposures to paired associates, where opportunity and incentive for active, elaborative processing of associations was minimized. As expected, correlations of learning performance with repetition priming were high relative to correlations with working memory. The Experiment 2 learning task involved repetitive exposure to concepts as in Experiment 1, but there was also ample opportunity and incentive for more active processing of the information. Subjects could study questions for as long as desired and could call up concept examples at any time. Consistent with these task differences, other measures such as working memory and semantic knowledge showed stronger relations to learning performance. Of importance though, repetition priming still correlated with learning and uniquely accounted for a small but significant amount of the learning variance.

GENERAL DISCUSSION

Most research on repetition priming has focused on understanding the nature of facilitation from repeating a processing event. The term, "implicit memory," has been used to describe this facilitation when it is independent of conscious recollection of the priming event (see Schacter, 1987). Given that implicit memory has been a relatively new topic of study, there is limited evidence regarding individual differences. The evidence that does exist primarily stems from research comparing the magnitude of repetition-priming effects for populations known to differ in explicit memory-test performance. Both developmental and neurological studies of this type have generally failed to find differences in repetition priming. As discussed earlier, a number of studies comparing normal and amnesic subjects have reported little or no difference in implicit memory performance, but large explicit memory differences (e.g., Graf & Schacter, 1985; Graf, Squire, & Mandler, 1984; Moscovitch, Winocur, & McLachlan, 1986; Warrington & Weiskrantz, 1970). Similarly, Light and Singh (1987) and Mitchell (1989) reported that young and old adults who differed on recall and recognition measures did not differ significantly with respect to repetition-priming effects.

One explanation for these findings would be that there are no systematic individual differences in implicit memory phenomena. After all, if such extreme groups do not differ, why would one expect differences within more homogeneous groups? Such an interpretation corresponds to Hasher and Zacks's (1979, 1984) assertion that individuals differ systematically on effortful processes but not on most automatic processes.

The current data contradict this interpretation. We found reliable individual differences within normal adults, and we found these differences to correlate with a variety of other learning and memory measures. The most viable interpretation of the developmental and neurological dissociations is simply that aging and certain neurological dysfunctions selectively affect explicit memory processes.

Having found individuals to differ systematically in repetition-priming effects, we addressed the question of whether these differences were of any consequence in more complex forms of cognition. Previous evidence had already suggested that repetition priming was related to procedural learning (e.g., Squire, 1986; 1987; Woltz, 1988). Here, we investigated whether repetition priming was related to declarative learning under repetitive practice conditions. In both studies we found evidence that individuals who showed greater repetition-priming effects were more efficient in acquiring new declarative knowledge.

There is substantial evidence suggesting that declarative knowledge acquisition often involves explicit, effortful memory processes, and that individual differences in active learning strategies such as elaboration are important in explaining learner differences (e.g., Kyllonen, Tirre, & Christal, 1991). In contrast, the evidence presented here suggests that some forms of declarative learning may involve more passive, implicit memory processes. We make no claim as to the relative importance of these two aspects of memory in declarative learning. We simply suggest that the role of implicit memory processes in learning may not be limited to procedural skill acquisition as might be concluded from previous evidence. Our data suggest that individual differences in implicit memory processes may be consequential in the acquisition of semantic knowledge, especially when learning ensues from repeated exposure to the new information.

REFERENCES

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

Ackerman, P.L. (1990). A correlational analysis of skill specificity: Learning, abilities, and individual differences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 883–901.

Anderson, J.R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, J.R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review, 94*, 192–210.

Christal, R.E. (1985). [Experimental working memory test battery WMT4]. Unpublished raw data.

Cohen, N.J., & Squire, L.R. (1980). Preserved learning and retention of pattern analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science, 210*, 207–209.

Daneman, M., & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450–466.

Department of Defense. (1984). *Test manual for the Armed Services Vocational Aptitude Battery* (DoD 1304.12AA). North Chicago, IL: U.S. Military Entrance Processing Command.

Feustel, T.C., Shiffrin, R.M., & Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General, 112*, 309–346.

Fleishman, E.A. (1972). On the relation between abilities, learning, and human performance. *American Psychologist, 27*, 1017–1032.

Forbach, G.B., Stanners, R.F., & Hochhaus, L. (1974). Repetition and practice effects in a lexical decision task. *Memory & Cognition, 2*, 337–339.

Glisky, E.L., & Schacter, D.L. (1987). Acquisition of domain-specific knowledge in organic amnesia: Training for computer-related work. *Neuropsychologia, 25*, 893–906.

Glisky, E.L., & Schacter, D.L. (1988). Long-term retention of computer learning by patients with memory disorders. *Neuropsychologia, 26*, 173–178.

Glisky, E.L., & Schacter, D.L. (1989). Extending the limits of complex learning in organic amnesia: Computer training in a vocational domain. *Neuropsychologia, 27*, 107–120.

Glisky, E.L., Schacter, D.L., & Tulving, E. (1986). Computer learning by memory-impaired patients: Acquisition and retention of complex knowledge. *Neuropsychologia, 24*, 313–328.

Graf, P., & Schacter, D.L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 501–518.

Graf, P., Squire, L.R., & Mandler, G. (1984). The information that amnesic patients do not forget. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 164–178.

Hasher, L., & Zacks, R.T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108*, 356–388.

Hasher, L., & Zacks, R.T. (1984). Automatic processing of fundamental information. *American Psychologist, 39*, 1372–1388.

Hill, L.B. (1957). A second quarter century of delayed recall or relearning at 80. *Journal of Educational Psychology, 48*, 65–68.

Jacoby, L.L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*, 21–38.

Jacoby, L.L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110*, 306–340.

Jacoby, L.L., & Hayman, C.A.G. (1987). Specific visual transfer in word identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 456–463.

Kirsner, K., Milech, D., & Standen, P. (1983). Common and modality-specific processes in the mental lexicon. *Memory & Cognition, 11*, 621–630

Kolers, P.A. (1976). Reading a year later. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 554–565.

Kyllonen, P.C., & Christal, R.C. (1990). Reasoning ability is (little more than) working memory capacity?! *Intelligence, 14*, 389–433.

Kyllonen, P.C., Tirre, W.C., & Christal, R.C. (1991). Knowledge and processing determinants of associative learning. *Journal of Experimental Psychology: General, 120*, 57–79.

Kyllonen, P.C., & Woltz, D.J. (1989). The role of cognitive factors in cognitive skill acquisition. In R. Kanfer, P.L. Ackerman, & R. Cudeck (Eds.), *Abilities, motivation, and methodology*. Hillsdale, NJ: Erlbaum.

Light, L.L., & Singh, A. (1987). Implicit and explicit memory in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 531–541.

Logan, G.D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology, 22*, 1–35.

Masson, M.E.J. (1986). Identification of typographically transformed words: Instance-based skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*, 479–488.

Mitchell, D.B. (1989). How many memory systems? Evidence from aging. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 31–49.

Moscovitch, M., Winocur, G., & McLachlan, D. (1986). Memory as assessed by recognition and reading time in normal and memory-impaired people with Alzheimer's disease and other neurological disorders. *Journal of Experimental Psychology: General, 115*, 331–347.

Nelson, T.O., & Narens, L. (1980). Norms of 300 general-information questions: Accuracy of recall, latency of recall, and feeling-of-knowing ratings. *Journal of Verbal Learning and Verbal Behavior, 19*, 338–368.

Ratcliff, R., Hockley, W., & McKoon, G. (1985). Components of activation: Repetition priming effects in lexical decisions and recognition. *Journal of Experimental Psychology: General, 114*, 435–450.

Roediger, H.L., & Blaxton, T.A. (1987). Effects of varying modality, surface features, and retention interval on priming in word fragment completion. *Memory & Cognition, 15*, 379–388.

Salasoo, A., Shiffrin, R.M., & Feustel, T.C. (1985). Building permanent memory codes: Codification and repetition effects in word identification. *Journal of Experimental Psychology: General, 114*, 50–77.

Scarborough, D.L., Cortese, C., & Scarborough, H.S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1–17.

Schacter, D.L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 501–518.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*, 1–66.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127–190.

Shimamura, A.P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology, 38A*, 619–644.

Shimamura, A.P., & Squire, L.R. (1984). Paired associate learning and priming effects in amnesia: A neuropsychological study. *Journal of Experimental Psychology: General, 113*, 556–570.

Shute, V.J. (1991). Who is likely to acquire programming skills? *Journal of Educational Computing Research, 7*, 1–24.

Singley, M.K., & Anderson, J.R. (1989). *The transfer of cognitive skill.* Cambridge, MA: Harvard University Press.

Sloman, S.A., Hayman, C.A.G., Ohta, N., Law, J., & Tulving, E. (1988). Forgetting in primed fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*, 223–239.

Squire, L.R. (1986). Mechanisms of memory. *Science, 232*, 1612–1619.

Squire, L.R. (1987). *Memory and brain.* New York: Oxford University Press.

Tulving, E., Schacter, D.L., & Stark, H.A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*, 336–342.

Warrington, E.K., & Weiskrantz, L. (1970). Amnesia: Consolidation or retrieval? *Nature, 228*, 628–630.

Winocur, G., & Weiskrantz, L. (1976). An investigation of paired-associate learning in amnesic patients. *Neuropsychologia, 14*, 97–110.

Woltz, D.J. (1988). An investigation of the role of working memory in procedural skill acquisition. *Journal of Experimental Psychology: General, 117*, 319–331.

Woltz, D.J. (1990a). Repetition of semantic comparisons: Temporary and persistent priming effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 392–403.

Woltz, D.J. (1990b). Decay of repetition priming effects and its relation to retention from text: A study of forgetting. *Learning and Individual Differences, 2*, 241–261.

Woltz, D.J., & Shute, V.J. (1993). *The time course of forgetting exhibited in repetition priming of semantic comparisons.* Manuscript submitted for publication.