Short-Term Memory and Working Memory : Do Both Contribute to Our Understanding of Academic Achievement in Children and Adults with Learning Disabilities?

H. Lee Swanson

J Learn Disabil 1994 27: 34
DOI: 10.1177/002221949402700107

Short-Term Memory and Working Memory: Do Both Contribute to Our Understanding of Academic Achievement in Children and Adults with Learning Disabilities?

H. Lee Swanson

Seventy-five children and adults with learning disabilities (age range = 5.0 to 42.10 yrs.) and 86 normally achieving children and adults (age range = 5.11 to 58.0 yrs.) were compared on short-term memory (STM) and working memory (WM) tasks to assess the relationship between STM and WM, and to test whether these measures independently relate to achievement. For both ability groups, the factor analyses indicated that STM and WM loaded on different factors, and the regressions and partial correlations showed that these different factors accounted for separate variance in reading comprehension and mathematics. Both STM and WM are important in understanding reading comprehension and mathematics performance in children and adults with learning disabilities; however, WM is more important for children and adults without learning disabilities. In contrast to WM, STM contributed minimal variance to word recognition in both ability groups. Overall, it was concluded that STM and WM do reflect different processes, both of which seem to separate the two ability groups. However, models of memory that view STM and WM as interchangeable, or STM in isolation, do not provide an adequate framework for capturing academic performance in children and adults with learning disabilities.

Short-term memory (STM) has been one of the most researched cognitive processes in children and adults with learning disabilities in the last 15 years (Swanson & Cooney, 1991). For example, most models of readers' processing performance argue that the temporary retention of information—STM—is important to reading recognition (e.g., Baddeley, Ellis, Miles, & Lewis, 1982; Bisiacchi, Cipolotti, & Denes, 1989; Ellis & Large, 1987; Jorm, 1983). Furthermore, several studies (see Jorm, 1983, and Hulme, 1992, for reviews) have implied that tasks that measure STM, such as digit- and/or word-span tasks, are important in differentiating readers with learning disabilities from readers without learning disabilities. In addition, tremendous credence is given to digit-span performance on the Wechsler intelligence tests for classifying students as learning disabled (e.g., Mishra, Shitala, Ferguson, & King, 1985). Unfortunately, STM tasks, such as digit- or word-span measures, do not always distinguish between good and poor readers (e.g., Cohen, 1981; Cohen & Heath, 1990; Perfetti & Lesgold, 1977). Likewise, the contribution of STM research to our understanding of the achievement of students with learning disabilities must be qualified for two reasons.

First, processes commonly attributed to STM are not the main source of differences between groups. Short-term memory is partly understood as a buffer, that is, a system of limited capacity for accumulating and holding segments of speech or orthographic units as they arrive during a listening or reading task (Crowder, 1976; Klapp, Marshburn, & Lester, 1983; Shankweiler & Crain, 1986). Material in short-term memory is maintained if it is restructured in some way, such as by rehearsal or item association (e.g., Cohen & Heath, 1990; Crowder, 1976; Salame & Baddeley, 1982; Shankweiler & Crain, 1986). Thus, the capacity limits of STM are modified by the use of rehearsal and/or the subject's chances of associating the item with previously stored information. It has been argued that rehearsal or organization deficits are major problems for students with learning disabilities (e.g., Bauer, 1979; Dallego & Moely, 1980). This notion has *not* held true across all studies, however; there are several reports in which differences in STM processes, such as rehearsal or chunking, do not consistently distinguish subjects with and without learning disabilities (e.g., Cohen, 1981; Cohen & Heath, 1990; Swanson, 1983). For example, some studies have found memory differences between students with and without learning disabilities when rehearsal was controlled (e.g., Cohen, 1981; Swanson, 1983), and when the organization of items was comparable between groups (e.g., Wong, 1978).

Second, correlations between STM and achievement have been generally poor for normally achieving students (e.g., see Dempster, 1985, for a review) and students demonstrating poor achievement (e.g., Felton & Brown, 1991; however, cf. Payne & Holzman, 1983). For example, Felton and Brown found no significant correlations between several STM measures and reading for children across a wide continuum of reading ability (*r*s ranged from .02 to .20 when the effects of age and IQ were partialed out). Poor correlations have also been found with adults. For example, Chiang and Atkinson (1976) found near-zero-order correlations between digit-span and scholastic aptitude scores, both verbal and mathematical. As suggested by Engle, Cantor, and Carullo (1992), one reason for these poor correlations is that STM, as reflected on the digit-span test, is sensitive to "rehearsal, grouping, and recognition of patterns that are idiosyncratic to digits and these elaborative strategies are probably not generalizable to cognitive tasks like reading" (p. 29).

In contrast to the above findings, verbal working memory (WM) tasks appear to consistently differentiate students with and without learning disabilities (e.g., Siegel & Ryan, 1989; Swanson, 1992, 1993b; Swanson, Cochran, & Ewars, 1989), and correlations between WM and achievement have been generally high (e.g., Daneman & Carpenter, 1980, reported correlations from .72 to .90 with reading comprehension; also see Daneman & Carpenter, 1983; Kyllonen & Christal, 1990; Masson & Miller, 1983). In these studies, WM is defined as the simultaneous storage and processing of information (e.g., Daneman, 1987; Kyllonen & Christal, 1990; Salthouse, 1990; Turner & Engle, 1989). Tasks that measure WM are those in which a person must hold a small amount of material in mind for a short time, while simultaneously carrying out further operations (see Note).

What is not apparent from the research comparing children and adults with and without learning disabilities is whether measures of WM predict academic performance of children and adults with learning disabilities better than STM measures. This issue is important because deficiencies in STM have served as a major impetus for several models of reading disabilities. These models have suggested that inefficient low-level processing at the word-recognition level is a critical factor in the weak comprehension abilities of individuals with reading disabilities (Shankweiler & Crain, 1986; Stanovich, 1986; Vellutino, 1979). Likewise, it is argued that high-order processing, such as executive processing, reflected on WM measures (Daneman, 1987), is *dependent* on STM skills (e.g., see Shankweiler & Crain, 1986, for a relevant discussion of the influence of low-order skills on high-level operations). Recent studies conducted outside the domain of reading, however, suggest that processes related to STM and WM may not overlap and that the two systems may operate independently of each other (e.g., Brainerd & Kingma, 1985; Brainerd & Reyna, 1988; Cantor, Engle, & Hamilton, 1991; Carlson, Khoo, Yaure, & Schneider, 1990; Klapp et al., 1983). Furthermore, it has been suggested that WM is particularly important to high-level cognition, such as reading comprehension and mathematics, whereas STM is less so (e.g., Daneman & Carpenter, 1980; Turner & Engle, 1989). In contrast, STM tasks may play an important role in low-level cognition, such as reading recognition (e.g., Jorm, 1983). Therefore, we might expect WM, at least for normally achieving readers, to be a more important factor than STM in predicting individual differences in reading comprehension and mathematics. The relative contribution of WM and STM to academic problems in children and adults with learning disabilities is less certain. Thus, the link between low-order processing, characteristic of a passive STM system, and high-order executive performance, characteristic of WM tasks, in samples that vary in academic ability needs to be clarified.

The purpose of this preliminary study is to determine if WM and STM contribute unique variance to achievement in children and adults with learning disabilities. It is also of interest to determine whether WM and STM are more important to some academic skills than others. The specific hypothesis tested is that WM and STM are independent measures and that WM is more likely to contribute to high-level cognition, such as reading comprehension and mathematics, than STM measures. It was of interest to determine if this pattern holds for both ability groups.

To address the issue of independence between STM and WM measures, the relationship between various memory measures was assessed, utilizing a model testing procedure. The particular model views long-term memory and WM as interrelated aspects of one system (see Swanson, 1992, 1993a, for further descriptions of the model). They are related because the content of WM is active long-term memory (LTM) representations (Anderson, 1983; Baddeley, 1986; Scheider & Detweiler, 1987; Shiffrin & Schneider, 1977). Thus, WM is a system in which information is temporarily held while being manipulated or transformed, whereas long-term memory consists of highly interconnected units of representation that include semantic and episodic information (Tulving, 1983). Working memory encoding occurs when long-term memory representations are fully activated, either by testing procedures that direct encoding or as a result of previous learning. On the other hand, STM is information maintained at a surface level that does not consciously rely on permanent knowledge structures for its operation (e.g., Engle et al., 1992). This independence of STM from LTM processing has been established in the literature (e.g., Gieselman, Woodward, & Beatty, 1982). Thus, STM is seen as functioning independently of these WM operations, because it operates as a passive storage system that makes minimal demands of long-term memory resources.

To test this model, a number of verbal and visual–spatial WM tasks were developed that were assumed to draw on different resources from long-term memory. Short-term memory tasks were also selected that require verbal and visual–spatial processing. The general prediction was that the factor patterns (i.e., task loadings on a particular factor) related to WM and short-term memory would not share variance. A two-factor model was tested, via an exploratory factor analysis, in which STM and WM are viewed as independent systems. Furthermore, to determine whether STM and WM memory make unique and independent contributions to achievement, several regression analyses were done in which WM was contrasted with STM on the criterion measures of reading and mathematics. It was predicted that the WM and STM measures would make unique contributions to achievement.

Method

Subjects

Eighty-six students without learning disabilities (47 males, 39 females) and 75 students with learning disabilities (49 males, 26 females) participated in this study. The children in this study were drawn from surrounding schools close to a university; the adults with learning disabilities attended a university education clinic. The majority of students with learning disabilities were tested at a university clinic. The normally achieving children were tested in public schools, and the adults were volunteers tested by school psychology students. Ethnicity was 95% and 81% white for children and adults without and with learning disabilities, respectively. All subjects were from middle-class to upper-class homes. Subjects in this study were part of a larger sample (N = 1,167) used to standardize WM measures for the Test of Mental Processing Ability (Swanson, in press).

To provide a representative sample, subjects were selected across a broad age range and according to performance, based on Wide Range Achievement Test–Revised (WRAT-R) (Jastak & Wilkinson, 1984) reading recognition scores. Children and adults were operationally defined as learning disabled if their reading recognition scores were at or below the 25th percentile on the WRAT-R and their scores (either verbal or performance) were above 85. Mathematics performance was not included in the selection criteria and, therefore, was left to covary. Children and adults were operationally defined as *not* having a learning disability if *both* reading and mathematics percentile scores on the WRAT-R were greater than 45 and verbal and nonverbal IQ scores were greater than 90. Classification of subjects with learning disabilities followed the Federal Register (1977) definition closely. In accordance with the provincial guidelines, a multidisciplinary team, including a school psychologist, participated in diagnoses. To qualify as learning disabled, a student had to have an intelligence test score in the average range and a processing deficit in reception, discrimination, association, organization/integration, retention, or application of information. No evidence or history of neurological abnormality, emotional disturbance, or cultural deprivation was apparent from previous school records. Although students with learning disabilities were selected for analysis because of primary problems in reading, it was difficult to find some subjects whose reading difficulties did not yield similarly low scores in mathematics. Thus, based on the WRAT-R scores shown in Table 1, students with learning disabilities in this study best reflect the combined reading and math subtype discussed by Fletcher (1985) and Siegel and Ryan (1989).

Children and adults with and without learning disabilities were not matched for verbal IQ because the sample would not be representative of the general population (Fletcher, 1985), resulting in a regression toward the mean. Furthermore, because it is generally known that readers with learning disabilities have lower verbal intelligence test scores than the normative sample (Fletcher, 1985), controls were placed on either the verbal or nonverbal IQ range (90 to 115) to ensure that children and adults with learning disabilities were not suffering from general intellectual difficulties or were functioning above or below the average range (85 to 115) of normal intelligence. The majority of subjects were administered the performance section of the WISC-R, although nonverbal IQ was established on some subjects using either the Raven Progressive Matrices Test (Raven, Court, & Raven, 1986) or Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983). None of the subjects were on medication during the time of the study. No significant differences occurred between groups on nonverbal IQ, $F(1,160) = .93$, $p > .25$. All subjects were administered the Peabody Picture Vocabulary Test–Revised (PPVT-R) (Dunn, 1981) to assess general vocabulary. A significant difference was found in vocabulary (see Table 1) between the ability groups, $F(1,160) = 31.57$, $p < .001$. Thus, PPVT-R scores were partialed out in the subsequent analyses.

The mean age of children and adults without learning disabilities was 14.50 (SD = 8.51; range = 5.11 to 53.6) and for those with learning disabilities was 14.58 (SD = 8.51; range = 5.0 to 42.00), and did not differ significantly, $F < 1$. Because of the large discrepancies in chronological age (CA) within ability groups, however, CA was partialed out in the subsequent analyses.

Aptitude, Achievement, and STM Measures

The Reading, Math, and Spelling subtests from the WRAT-R were administered. Three subtests from the Peabody Individual Achievement Test–Revised (PIAT-R) (Dunn & Markwardt, 1988) were also administered: Mathematics, Reading Recognition, and Reading Comprehension. These subtests were administered because they represent a continuous range of items increasing in difficulty. A multiple-choice format is used in all subtests, thereby controlling for difficulties subjects may have in accessing words.

The PPVT-R was also administered. This test requires the examiner to read a stimulus word, and the subject responds by pointing to the picture illustrating the word. Items are arranged in ascending order of difficulty. Test-retest reliability is .97.

Four subtests from the Detroit Test of Learning Aptitude (Hammill, 1985) were selected to assess short-term memory because of their reported high reliability. Two subtests primarily represent verbal processing (Sentence Imitation, Word Sequence) and two represent nonverbal (or low verbal) processing (Design Reproduction, Object Sequence). For the Sentence Imitation subtest, words are read aloud to the subject (approximately one word a second), and after hearing the sentence, he or she repeats it. Sentences increase in word length from 6 to 19 words. The Word Sequence subtest presents a series of unrelated words of increasing length. The Design Reproduction subtest presents increasingly complex pictures of a geometric form; after the stimulus is removed, the subject draws it from memory. The Object Sequence subtest presents a series of pictures that increase in set size; the pictures are withdrawn and the subject's task is to recreate them correctly. Reliabilities vary on the subtests from .52 to .92. A common measure of STM, the Digit Span subtest from the Wechsler series, was also administered.

Means and standard deviations for the psychometric data are shown in Table 1.

Working Memory Battery

Eleven verbal and visual-spatial WM tasks were used from the Mental Processing Potential Test (Swanson, in press). A critical feature of all tasks is that they require the maintenance of some information during the processing of other information. The processing of information is assessed by asking children and adults a comprehension question about the material to be remembered, whereas storage is assessed by accuracy of item retrieval. Thus, all WM tasks were designed to conform with Baddeley's (1986) stipulations that they "require simultaneous processing and storage of information" and "measure various contents" (pp. 34–35).

The WM tasks reflect a broad array of processing (verbal and visual-spatial), resource demands (semantic and episodic), and retrieval conditions (prospective and retrospective). A description of each task follows. (The number beside each WM task is the order in which the task was administered in the battery.)

Task 1—Rhyming. The purpose of this task is to assess the participant's recall of acoustically similar words. The participant listens to sets of words that rhyme, with each successive word in the set presented every 2 seconds. The dependent measure is the number of sets recalled. Before recalling the words, the subject is asked whether a particular word was included in the set. For example, the subject is presented the words *lip–slip–clip* and then asked if *ship* or *lip* was presented in the word set. He or she is then asked to recall the previously presented words (*lip–slip–clip*) in order. There are nine word sets, each containing from 2 to 14 monosyllabic words (range = 0 to 9).

Task 2—Visual Matrix. The purpose of this task is to assess the participant's ability to remember visual sequences within a matrix. The participant is presented a series of dots in a matrix and allowed 5 seconds to study it. The matrix is removed and the participant is asked a process question: "Are there dots in the first column?" To ensure the understanding of column, the experimenter points to the first column on a blank matrix (a grid with no dots). After answering the process question, the participant is asked

TABLE 1
Mean Standard Scores on Aptitude and Achievement Measures Across Study Sample

	With learning disabilities		Nonlearning disabled	
Intelligence				
Nonverbal IQ	99.78	(10.23)	101.00	(5.38)
Language				
Peabody Picture Vocabulary Test–Revised	95.81	(9.90)	105.72	(12.13)
Achievement				
Wide Range Achievement Test–Revised				
Reading recognition	81.79	(9.06)	111.21	(7.47)
Mathematics	92.41	(13.49)	106.43	(12.24)
Spelling	83.94	(11.29)	109.39	(10.00)
Peabody Individual Achievement Test–Revised				
Reading recognition	81.45	(6.23)	105.15	(13.50)
Reading comprehension	86.02	(8.79)	104.76	(12.78)
Mathematics	89.59	(13.57)	104.58	(14.13)

Note. Numbers in parentheses represent standard deviations.

to draw the dots in the correct boxes on the blank matrix. The range of difficulty is a matrix of 4 squares and 2 dots to a matrix of 45 squares and 12 dots. The dependent measure is the number of matrices recalled correctly (range = 0 to 11).

Task 3—Auditory Digit Sequence. The purpose of this task is to assess the participant's ability to remember numerical information embedded in a short sentence. Prior to stimulus presentation, the participant is shown a figure depicting four strategies for recalling numerical information. These strategies are pictorial representations of rehearsal, chunking, associating, and elaborating of information. (A verbal description of the strategies, prior to administration of the targeted items, utilizes the same format as Tasks 4, 7, 8, 10, 11.) After all strategies have been explained, children and adults are then presented numbers in a sentence context. A sample sentence (Item 3) is, "Now suppose somebody wanted to have you take them to the supermarket at *8 6 5 1* Elm Street." Numbers are presented one every 2 seconds. Children and adults are then presented a process question: "What is the name of the street?" They are then told they must recall the numbers in the sentence in order shortly *after* they select from (i.e., point to) a pictorial array (see Figure 1) representing the strategy that best approximates how they will attempt to remember the information. No further information about the strategies shown in the picture is provided. The range of recall difficulty is 3 digits to 14 digits, and the dependent measure is the number of sets recalled correctly (range = 0 to 9).

Task 4—Mapping and Directions. The purpose of this task is to determine whether the participant can remember a sequence of directions on a map that is void of labels. The experimenter presents the participant with a street map with lines connected to a number of dots that illustrate the direction a bike would go to get out of the city; the dots represent stop lights and the lines the direction the bicycle (or car) should go. The map is removed after 10 seconds; the participant is then asked a process question: "Were there any dots in the first street (column)?" He or she is asked to point to the strategy (picture) he or she will probably use to remember the street directions. Strategies are pictorial representations (with the same format as in Task 3) of elemental, global, sectional, or backward processing of patterns. Finally, the participant is asked to draw on another map the street directions (lines) and stop lights (dots). The range of difficulty includes dots that range in number from 4 to 19. The dependent measure is the number of maps drawn correctly (range = 0 to 9).

Task 5—Story Recall. The purpose of this task is to assess the participant's ability to remember a series of episodes presented in a paragraph. The experimenter reads a paragraph, asks a process question, and then asks the participant to recall all the events that have

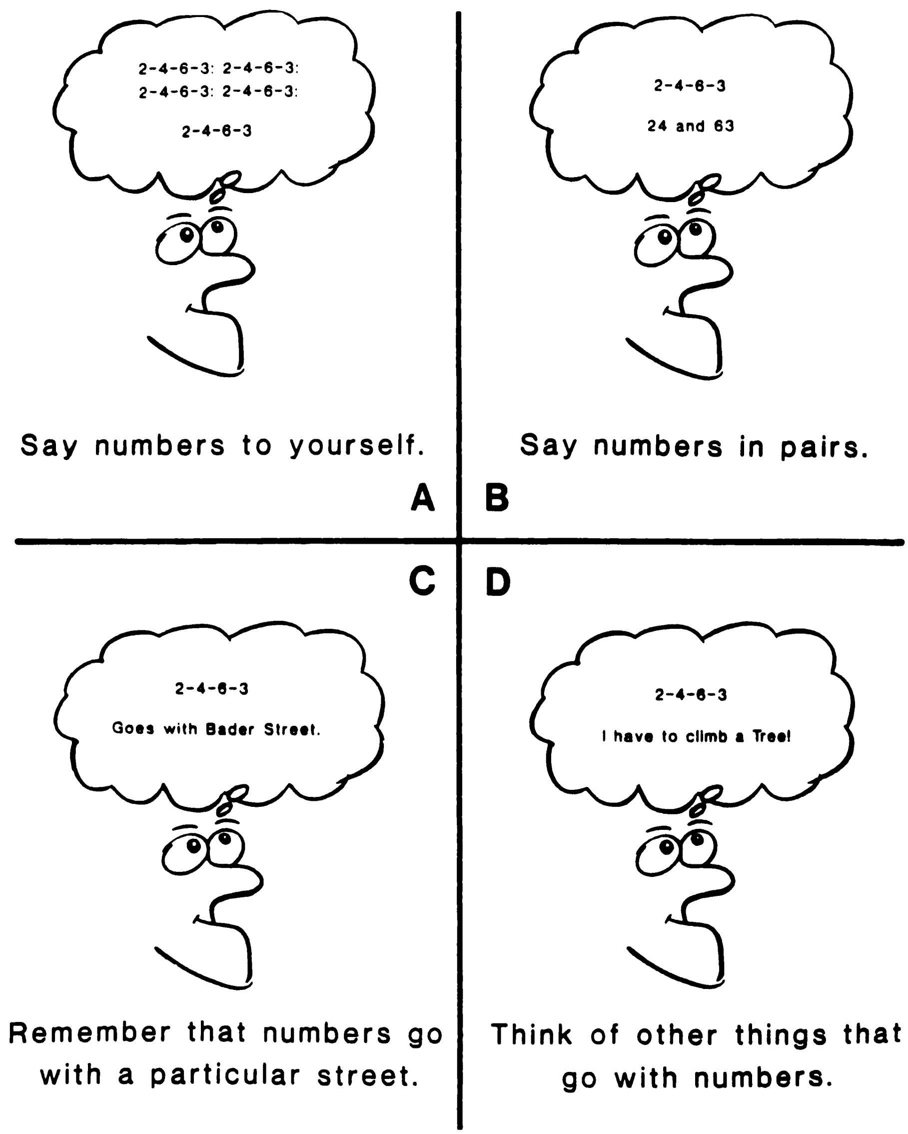

FIGURE 1. Illustration of strategy choices for the Auditory Digit Sequence Task.

occurred, in order. The paragraph is a 12-sentence story; each sentence includes two idea units and 8 to 11 words. The paragraph is related to the famous battle of the Armada, in which a small fleet of English ships beat the Spanish fleet. For the process question the subject is asked, "Who won the battle?" The dependent measure is the number of sentences recalled correctly and in order (range = 0 to 11). For a sentence to be recalled correctly it must include two idea units and occur in the correct order.

Task 6—Picture Sequence. The purpose of this task is to assess the child's and adult's ability to remember an increasing sequence of shapes, in order. Pictures of shapes are presented on a series of cards and displayed for 30 seconds. The cards are gathered, a process question is asked, and then the participant is instructed to arrange those cards in the correct sequence. The process question is, "Is this card (distractor card) or this card (card selected from another set) the one I presented?" The dependent measure is the number of sets of cards reproduced correctly. The set size varies from 3 to 15, and scores vary from 0 to 9.

Task 7—Phrase Sequence. The purpose of this task is to determine the child's and adult's ability to remember isolated phrases. They are instructed to remember all phrases, but not necessarily in order. An increasing number of phrases is presented. After each presentation, a process question is asked, and the participant is informed that he or she must remember this information shortly after selecting the best strategy to help him or her remember the material. The strategies are pictorial representations of elaborating, indexing, associating, and chaining information. A sample sequence of phrases (Set 3) is *a flowing river, a slow bear, a growing boy, a gripping tire.* A sample process question is, "Are the words about a bear or boat?" The range of difficulty is 2 phrases to 12 phrases. The dependent measure is the number of sets recalled correctly (range = 0 to 9).

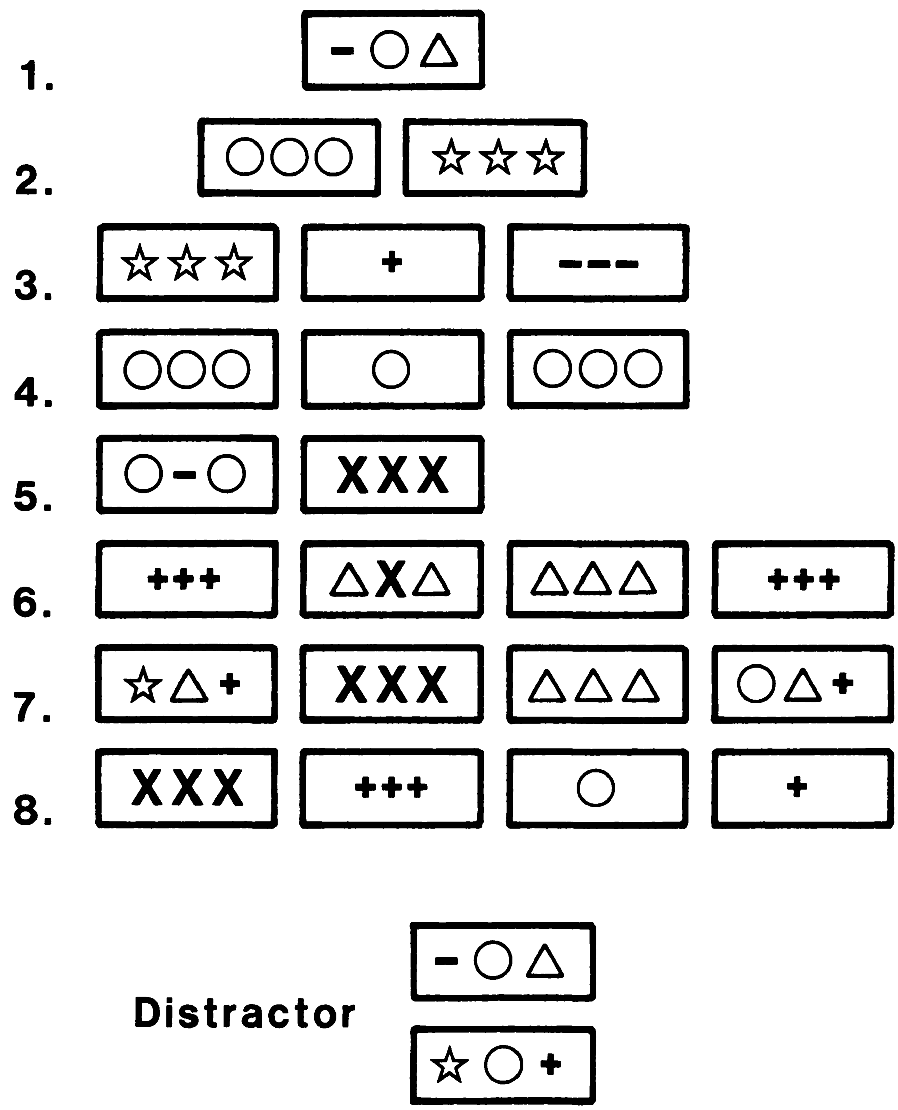

FIGURE 2. Array of stimulus cards for the Spatial Organization Task.

Task 8—Spatial Organization. The purpose of this task is to determine the participant's ability to remember the spatial organization of cards that have pictures of various shapes. These cards are ordered in a top-down fashion, as shown in Figure 2. The presentation of this task includes five steps: (a) A description of each strategy is provided; (b) the experimenter presents the sequenced cards in their correct organization and allows the participant 30 seconds to study the layout; (c) the experimenter gathers up the cards, shuffles them, then asks a process question; (d) the experimenter asks the participant to select a strategy that he or she will use to remember the cards; and (e) the participant is directed to reproduce each series of cards in the order in which they were given. For the process question, prior to the participant placing the cards in the correct rows and order, the experimenter takes out the first card (Row 1) and last card (Row 8) and asks, "Which card came first?" Following the same format as Task 3, the strategies to be selected are pictorial representations focusing on imagery, pattern similarity, pattern dissimilarity, and visual sequencing. The dependent measure is the number of rows recalled correctly (range = 0 to 8).

Task 9—Semantic Association. The purpose of this task is to determine the participant's ability to organize words into abstract categories. The participant is presented one word every 2 seconds, asked a process question, and asked to recall the words that go together. For example, Set 3 includes *shirt, saw, pants, hammer, shoes,* and *nails.* The participant is directed to retrieve the words that go together (i.e., *shirt, pants,* and *shoes; saw, hammer,* and *nails*). The process question is, "Which word, *saw* or *level,* was said in the list of words?" Thus, the task requires the participant to transform information that was encoded serially into categories during the retrieval phase. The participant is told that the words can be recalled in any temporal order within a particular category, provided that the words are related to the appropriate category. The range of difficulty is two categories of two words, to five categories of four words. The dependent measure is the number of sets recalled correctly (range = 0 to 8).

Task 10—Semantic Categorization. The purpose of this task is to determine the participant's ability to remember words within categories. One word is presented every 2 seconds, and the participant is told that she or he must remember this information shortly after telling the examiner how she or he will attempt to remember the material. The participant is asked to recall the category name *first,* and then any word that went with that category. Prior to recall of the words, however, the participant is asked a process question and then asked to select a strategy that will facilitate the recall of the words. A sample item (Item 3) is : "*Job,* teacher, fireman, policeman; *season,* summer, winter, fall." A sample process question is, "Which word, *soldier* or *summer,* was presented?" The four pictorial examples of strategies include top-down superordinate organization, inter-item discrimination, inter-item associations, and subjective organization. The range of difficulty for the sets is from two words within one category, to eight categories with three words within each (range = 0 to 8 sets).

Task 11—Nonverbal Sequencing. The purpose of this task is to determine the participant's ability to sequence a series of cards with pictures of nonsense shapes. The participant is presented a series of cards whose organization is not provided by the experimenter. The participant is allowed to organize the cards into any rows he or she would like, with the stipulation that a certain number of cards be included in each row. The first row must have one card; the second row, two cards; the third row, four cards; the fourth row, six cards; and the fifth and sixth rows, eight cards each. The participant is given 2 minutes to place the cards in rows. After the rows have been established and the participant has studied them for 30 seconds, the cards are gathered up, and then he or she is asked a process question: "Is this card (card in the first row) or this card (distractor card randomly chosen) the one you put into the first row?" The participant is then asked to select the picture that best represents how she or he is planning to remember this sequence. The four strategies depicted in the illustrations include images of hierarchical association, subordinate association, global sorting, and bottom-up sequencing. The experimenter then inserts two distractor cards, shuffles the cards, and asks the participant to reproduce the cards by each row. The range of difficulty is the recall of one card per row to eight cards per row. The dependent measure is number of cards placed correctly in each row (range = 0 to 6).

Table 2 shows how the WM and STM tasks were categorized. The simplest categorization was in terms of tasks that primarily require verbal versus visual-spatial processing. For example, WM Tasks 1, 3, 5, 7, 9, and 10 require primarily auditory verbal processing (i.e., listening and verbal recall), and Tasks 2, 4, 6, 8, and 11 require nonverbal or low-verbal visual processing (i.e., the manipulation of pictures or shapes).

Another categorization of WM tasks relates to *how information is forgotten.* For example, suppose an individual is to recall a story and forgets to include some critical episode in the story just heard. This may be because the story to which the person listened required little conscious control on the child's or adult's part, or because the child or adult attempted to "over-learn" information and failed to attend to the action-event sequence. This same story, of course, could be forgotten in a different way if a child or adult knew he or she could reflect on the story and develop a plan of action for retrieving the story at a later time. The first kind of memory difficulty reflects a *retrospective* memory failure, and is represented in Tasks 1, 2, 5, 6, and 9. These memory tests require that information be presented to the subject, who then recalls the series of items immediately after presentation. The second type of error relates to, for lack of a better term, *prospective* memory, and is represented in Tasks 3, 4, 7, 8, 10, and 11. This is a memory error that reflects the recall of events at a future point in time (see Baddeley & Wilkins, 1985, for a broader definition of this term). To assess memory errors of this type, it was necessary in the present study to focus on the type of strategies the child or adult used to prepare for the eventual recall of information. This was accomplished by first presenting children and adults with pictorial representations of strategies that might be helpful for retrieving items. After they were presented these strategies, stimulus items to be recalled were administered. Prior to retrieval, children and adults were asked a question about items, as well as to select the strategy in a picture they thought would help them retrieve the stimulus items.

Working memory tasks were designed to tap resources from episodic and semantic memory. *Episodic memory* is defined as a conscious recollection of "personally experienced events and their temporal relations" (Tulving, 1983, p. 387). Episodic tasks developed in the present study include story sequencing (Task 5) and picture sequencing (Task 6), which are standard measures of episodic memory (cf. Tulving, 1972). *Semantic memory* is also available to consciousness, but unlike episodic memory, it is not directly tied to spa-

TABLE 2
Mean Raw Scores for Working Memory and Short-Term Memory Tasks

	With learning disabilities		Nonlearning disabled		
Type of score	***M***	***SD***	***M***	***SD***	***F*-ratio (ANCOVA)**
Working Memory					
Listening (level score)					
Sentence span	1.31	1.18	2.14	2.00	9.28**
	(−.30)		(.19)		
Retrospective-verbal					
Rhyming	1.29	1.06	2.02	1.18	6.93**
	(−.23)		(.19)		
Story retelling	4.44	3.13	4.95	3.49	1.10 *ns*
	(.07)		(−.09)		
Semantic association	.90	1.17	1.61	1.69	5.31*
	(−.19)		(.18)		
Retrospective visual–spatial					
Visual	1.29	1.06	3.96	1.39	2.87**
Matrix	(−.13)		(.14)		
Picture	1.65	1.03	2.17	1.10	2.59 *ns*
Sequence	(−.16)		(.11)		
Prospective-verbal					
Auditory	1.40	1.31	2.47	1.76	7.86**
Digit sequence	(−.25)		(.19)		
Phrase	1.65	1.03	1.04	1.03	.02 *ns*
Sequence	(−.03)		(.01)		
Semantic	1.48	.97	2.10	1.09	8.58**
Categorization	(−.27)		(.21)		
Prospective Visual–spatial					
Mapping & direction	1.32	1.20	2.02	1.76	.86 *ns*
	(−.06)		(.09)		
Spatial organization	1.33	1.23	1.77	1.38	1.08 *ns*
	(−.11)		(.07)		
Nonverbal sequencing	2.02	2.04	2.01	1.60	.00 *ns*
	(−.04)		(−.03)		
Short-Term Memory					
Verbal measures					
Sentence imitation	13.33	4.64	16.51	5.48	2.00 *ns*
	(−.11)		(.10)		
Word sequence	11.32	3.88	14.37	5.71	6.39*
	(−.21)		(.18)		
Digit span	9.60	7.87	9.23	1.67	.16 *ns*
	(−.04)		(.03)		
Visual–spatial measures					
Design reproduction	28.63	16.23	34.44	16.57	6.52*
	(−.22)		(.20)		
Object sequence	33.56	16.37	37.32	11.35	.99 *ns*
	(−.07)		(.09)		

Note. Numbers in parentheses = least squares mean *z* score with age and PPVT-R partialed out.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

tial and temporal autobiographical contexts. Semantic memory is defined as a "mental thesaurus, organized knowledge a person possesses about words and other verbal symbols" (Tulving, 1972, p. 386). Tulving (1983) later expanded it to include an "organism's knowledge of the world" (p. 388), to encompass an individual's organized knowledge about nonverbal information. Sample semantic measures used in the present study include semantic categorizing (Task 10), semantic association (Task 9), and phrase recall (Task 7).

Reliability Analysis. Internal reliability estimates on scores for the 11 subtests varied from .80 to .98, whereas overall reliability (summed score across tasks) was .96. Reliability estimates for memory-span scores were derived from Cronbach's alpha formula as measures of internal consistency.

Sentence-Span Measure. An adaptation of the Sentence Span Task (Swanson et al., 1989), a common measure of WM (Daneman, 1984; Daneman & Carpenter, 1980; Turner & Engle, 1989; see Baddeley, Logie, & Nimmo-Smith, 1985, for a critical discussion), was also administered. This task requires the presentation to subjects of groups of sentences, which they read either aloud or silently and try to simultaneously understand the passage and remember the last word of each sentence. The number of sentences in the groups gradually increases. After the presentation of each group, the subject answers a question about a sentence and then recalls the end word. Working memory capacity is defined as the largest group of end words recalled. The sentence-span measure, unlike more traditional measures of short-term memory capacity, successfully predicts performance on reading tasks, as well as performance on a variety of other, related tasks (Daneman & Carpenter, 1980; Daneman & Green, 1986; Masson & Miller, 1983). The validity of this measure for a sample with learning disabilities has been previously established (Swanson et al., 1989).

Materials for the Sentence Span Task are unrelated declarative sentences, 7 to 10 words in length. The mean sentence-reading grade level was approximately 3.8. The sentences are arranged randomly into sets of two, three, four, or five. After listening to the sentence sets, the participant is asked to recall the last word of several sentences, and to answer a comprehension question about one of the sentences. Examples of the sentences for recalling the last word in a series of three sentences are:

1. We waited in line for a ticket.
2. Sally thinks we should give the bird its food.
3. My mother said she would write a letter.

To ensure that the children and adults comprehended the sentences (i.e., processed their meaning and did not merely try to remember the target word or treat the task as one of short-term memory), they were required to answer a question after each group of sentences was presented. Questions were related to a randomly selected sentence (but never the last sentence) in the set. For the three-sentence set, for example, they were asked, "Where did we wait?" Equivalent-form reliability on this measure was .92.

Procedure

All tests were administered individually by graduate students in school psychology or tests and measurement classes. Training of graduate students was done in one 3-hour session. Testing of subjects was done in approximately three 1-hour sessions at different periods. All psychometric tests were administered first, followed by the memory tasks. Administration procedures followed the standardization test manual. All items on WM tasks were administered until an error occurred. For students who were not able to respond correctly to the process question, item recall was not requested and their response was scored as zero.

Results

Table 2 presents the means and standard deviations of raw (span-level) scores for memory measures. A scale score is provided for the Digit-Span test. For the subsequent analysis, all measures were converted to z scores *within* each age group represented in the study. To control for age effects, seven age groups (5 to 6, 7 to 8, 9 to 11, 12 to 15, 16 to 18, 19 to 30, greater than 31) were created to calculate z scores. No significant differences were found between groups on z scores as a function of gender and ethnicity, so these variables were not investigated further.

Group Comparison

A MANCOVA was computed across the WM and STM measures. Chronological age and PPVT-R scores were the covariates. The results indicated that scores of students without learning disabilities were superior to those of students with learning disabilities, $F(17,132) = 2.33$, $p < .01$. As shown in Table 2, an ANCOVA indicated that significant differences (ps $< .05$) occurred between ability groups across the majority (five of seven tasks) of verbal WM tasks. No significant effects were found between ability groups on the visual-spatial WM measures, except for the visual matrix task. Only two out of five STM tasks—one verbal and one visual-spatial—were significantly different between ability groups. Overall, the findings suggest that subjects with and without learning disabilities are statistically comparable on most visual-spatial WM and STM measures, but vary considerably across the majority of verbal WM measures. To determine the single best discriminator among ability groups, composite scores (mean z scores across tasks) based on the categories shown in Table 2 for verbal and visual-spatial memory were computed for STM and WM measures. These composite scores were submitted to a Forward Stepwise Discriminant Analysis. The criterion variable was ability group classification, and the predictor variables were the composite scores for the six categories. The single best predictor of ability group classification was the prospective verbal WM composite score, partial R^2 = .15, $F(1,157)$ = 27.30, p < .0001. All other measures contributed less than 5% of the variance.

Intercorrelations

The correlations between the WM and STM measures within ability group, partialed for age and PPVT-T scores, are shown in Table 3. The intercorrelation patterns are as expected; that is, the majority of WM measures are more intercorrelated with each other than with STM measures.

To interpret the intercorrelation patterns in Table 3, a series of maximum-likelihood analyses (Joreskog & Sorbom, 1984) was computed on WM and STM measures. To enhance the reliability of these comparisons, composite scores for verbal and visual–spatial memory (mean z scores across tasks) were again computed for STM and WM measures. To test the assumption that the WM tasks are separate from STM, maximum-likelihood estimates were obtained for the two-factor model, as well as the competing one- and three-factor models. For children and adults without learning disabilities, the likelihood-ratio chi-square test yields χ^2 (9, N = 86) = 25.34, p < .01, for the one-factor model; χ^2 (4, N = 86) = 1.72, p > .05, for the two-factor model; and χ^2 < 1.0 for the three-factor model. For the sample with learning disabilities, the likelihood-ratio chi-square test yields χ^2 (9, N = 75) = 12.29, p > .05, for the one-factor model; χ^2 (4, N = 75) = 4.13, p > .05, for the two-factor model; and χ^2 < 1.0 for the three-factor model. The two-factor structure for the confirmatory analysis is shown at the bottom of Table 3. Using .30 and above as a meaningful factor loading, the results shown at the bottom of Table 3 produce two distinct WM and STM factors for the sample without learning disabilities. In contrast, the two factors that emerge for the sample with learning disabilities reflect a division of verbal and visual–spatial WM. Short-term memory tasks did not load meaningfully on either factor. Thus, a three-factor solution may better represent the sample with learning disabilities. Although the three-factor model (visual–spatial WM, verbal WM, STM) did yield a separate factor for the STM measures for the sample with learning disabilities, it was necessary to test the above factor solutions further.

As in any model-fitting procedure, it was necessary to supplement the statistical test with a coefficient index that reflected, with a percentage, how far the model was from a perfect fit. For the chi-square goodness-of-fit test statistic of the current model, Bentler and Bonett (1980) developed an index, in proportional terms, for the degree to which the model departs from a perfect fit of the data. The coefficient of fit is a simple function of the chi-square test for the theoretical model under consideration and the chi-square test for a model that hypothesizes that the variables are uncorrelated in the population. For children and adults without learning disabilities, the goodness-of-fit index was computed from the null model (which hypothesizes that the variables are uncorrelated) in the population χ^2 (15, N = 86) = 74.09, and from the current two-factor model, χ^2 (4, N = 86) = 1.72, as 74.09 − 1.72/74.09 = .98. Thus, the model is 98% of the way to a perfect fit. For the sample with learning disabilities, the goodness-of-fit index was .94 (73.38 − 4.13/73.38). Further testing of this model included an analysis of the χ^2/df ratio, the root mean square residual, and the Tucker-Lewis index (TLI). The χ^2/df ratio provides information on the relative efficiency of the alternative model in accounting for the data (Marsh, Balla, & McDonald, 1988). Values of 2.0 or less are interpreted to represent an adequate fit. The present two-factor model is .43 and 1.03 for the sample without and with learning dis-

TABLE 3
Intercorrelation Matrix and Factor Solution
for Confirmatory Analysis with Age and Vocabulary Partialed-out

Tasks	1	2	3	4	5	6
Working memory[a]						
1. Retro-verbal	—	.15	.51	.21	.10	.13
2. Retro-visual	.21	—	.52	.41	.01	−.04
3. Prosp-verbal	.32	.54	—	.45	.20	.18
4. Prosp-visual	.17	.25	.23	—	.03	.26
Short-term memory						
5. Verbal	.26	.09	.21	.19	—	.07
6. Visual–spatial	.16	.004	.08	.01	.47	—

	Nondisabled		With learning disabilities	
Optimal solution factor (rotated)	1	2	1	2
Working memory				
1. Retro-verbal	.36	.23	.20	.54
2. Retro-visual	.70	−.03	.99	−.08
3. Prosp-verbal	.77	.08	.58	.75
4. Prosp-visual	.32	.13	.43	.27
Short-term memory				
5. Verbal	.18	.87	.03	.24
6. Visual–spatial	.03	.53	−.01	.29

[a]Coefficients on the left of the diagonal are students without learning disabilities (LD) and those on the right are students with LD. Prosp = prospective; Retro = retrospective.

abilities, respectively. The root mean square residual (RMSR) is a measure of average residual correlation (Joreskog & Sorbom, 1984). Smaller values (.10 or less) are reflective of a better fit. The RMSRs in the present study were .037 and .064 for the samples without and with learning disabilities, respectively. The TLI scales the chi-square from 0 to 1, with 0 representing the fit of the null model (Bentler & Bonett, 1980), which assumes that the variables are uncorrelated, and 1 representing the fit of a perfectly fitting model. Large values indicate a better fit. Furthermore, this measure is independent of sample size. The nonstandardized (i.e., values may be > 1.0) TLIs in the present study were 1.14 and .991 for the samples without and with learning disabilities, respectively. Overall, the results suggest that a two-factor model, in which WM and STM operate independently of each other, provides an adequate fit to the data. Thus, the two-factor model appears to be an adequate representation of performance for children and adults with and without learning disabilities.

Correlations with Achievement

Correlations between achievement measures and WM and STM within ability groups are shown in Table 4. Because the previous analysis supported a two-factor model, composite scores (means of standard scores across tasks) were computed across STM and WM tasks. As shown in Table 4, WM composite scores are more likely to be significantly related to academic performance than to STM measures in children and adults without learning disabilities. In contrast, both STM and WM seem to contribute to achievement in children and adults with learning disabilities. One explanation for the correlation of WM measures with achievement is that individuals who score high on tests of vocabulary tend to score high on WM span measures (Daneman & Green, 1986) and on measures of achievement (e.g., Dixon, LeFevre, & Twilley, 1988); therefore, one would expect some generalized relationship between WM and achievement measures. Thus, correlations between memory and achievement measures were computed with performance on the PPVT-R partialed out in the analysis. As shown in Table 4, three of six correlations for WM and one of six for STM remain significant for the sample without learning disabilities. This finding suggests that the correlation patterns for the WM and high-level tasks (i.e., math and comprehension) are not merely a function of word knowledge. A different pattern emerges for the sample with learning disabilities. Both WM and STM maintain significant coefficients with math and reading comprehension measures, but not with reading recognition subtests.

It could be argued that because students with learning disabilities suffer verbal coding deficits (e.g., Shankweiler et al., 1979; Vellutino, 1979), they may favor visual-spatial processing over verbal processing, and, therefore, the correlations between WM and reading recognition may be different between ability groups if the type of processing is taken into consideration. Furthermore, it could be argued that because the factor analysis yielded different loadings related to the WM measures for the two ability groups, a focus on separate composite scores by the categories represented in Table 2 might produce different ability group patterns in correlations. Correlations between WM component scores and achievement, as a function of verbal and visual-spatial processing, are shown in Table 5. Correlations were partialed for the influence of vocabulary (PPVT-R scores). To simplify Table 5, reading recognition and mathematics performance from the WRAT-R were analyzed. Reading-recognition and math scores from the WRAT-R, rather than the PIAT-R, were selected because they are measures commonly used to classify reading and math problems (Fletcher, 1985; Siegel &

TABLE 4
Correlations Between Achievement and Memory Measures

	Nonlearning disabled (n = 86)				With learning disabilities (n = 75)			
	WM		STM		WM		STM	
WRAT-R								
Reading	.37**	(.16)	.20	(.02)	.23*	(.11)	.17	(.03)
Math	.40**	(.28*)	.34**	(.25*)	.38**	(.33**)	.41**	(.36**)
Spelling	.24*	(.11)	.26*	(.18)	.44**	(.39**)	.45**	(.40**)
PIAT-R								
Math	.36**	(.24*)	.21*	(.11)	.42**	(.33**)	.40**	(.29*)
Reading Recognition	.22*	(.01)	.20	(.05)	.33**	(.26*)	.28*	(.20)
Reading Comprehension	.43**	(.30**)	.17	(.05)	.32**	(.27**)	.42**	(.37**)

Note. Numbers in parentheses = coefficients with word knowledge (PPVT-R) scores partialed out. WM = working memory; STM = short-term memory.
*$p < .05$. **$p < .01$.

TABLE 5
Correlations Between Component Scores and Achievement with PPVT-R Scores Partialed Out

Component	Reading recognition		Reading comprehension		Mathematics	
	NLD	LD	NLD	LD	NLD	LD
Working memory						
Retrospective-verbal	−.06	.03	.21*	.13	.13	.40**
Retrospective-visual	.16	−.02	.14	−.001	.16	.32**
Prospective-verbal	.22*	.26*	.35**	.20	.31**	.35**
Prospective-visual	.17	.02	.18	.27*	.30**	.26*
Short-term memory						
Verbal	.10	−.18	.33**	.30**	.24*	.33**
Visual–spatial	.007	.20	−.05	.23*	.20	.08

Note. PPVT-R = Peabody Picture Vocabulary Test–Revised. NLD = nonlearning disabled; LD = with learning disabilities.
$^*p < .05$. $^{**}p < .01$.

Linder, 1984; Siegel & Ryan, 1989). Reading comprehension from the PIAT-R was also analyzed.

The results shown in Table 5 yield three important findings: First, both verbal and visual–spatial STM were weakly related to reading recognition in both ability groups. In contrast, prospective verbal WM scores for both ability groups were related to reading recognition. Second, verbal STM for both ability groups was significantly related to comprehension and mathematics. Finally, no modality-specific pattern was found, suggesting that verbal processing was better correlated to achievement in the sample with learning disabilities than in the nondisabled sample. That is, no significant differences, via a Fisher *z* score transformation, emerged in the size of the coefficients between ability groups. The only modality-specific pattern that emerged was when a comparison was made of the frequency of significant correlations. Significant correlations emerged between prospective visual–spatial WM and reading comprehension and visual–spatial STM and reading comprehension for the sample with learning disabilities, whereas no such pattern emerged with the comparison group.

Stepwise Regression

To determine whether the six composite scores shown in Table 5 contributed unique variance to reading recognition, reading comprehension, and mathematics, a stepwise regression analysis using a forward selection technique was done (Maracuilo & Levin, 1983). The six composite scores were entered in order of their highest squared partial correlation. For the sample with learning disabilities, significant predictors of reading recognition were prospective verbal WM, R^2 = .07, $F(1,71) = 5.27$, $p < .05$; verbal STM, increment in R^2 = .06, $F(1,70) = 4.91$, $p < .05$; and retrospective verbal WM, increment in R^2 = .05, $F(1,69) = 3.98$, $p < .05$. Significant predictors of reading comprehension were verbal STM, R^2 = .09, $F(1,71) = 7.04$, $p < .01$; and verbal retrospective WM, increment in R^2 = .07, $F(1.70) = 5.79$, $p < .05$. Significant predictors of mathematics were prospective verbal WM, R^2 = .12, $F(1,71) = 9.92$, $p < .01$; and verbal STM, increment in R = .07, $F(1,70) = 6.12$, $p < .05$. No other variables predicted the criterion measures. Overall, the results indicated that both verbal STM and verbal WM contributed unique variance to the three achievement measures. Approximately 18%, 16%, and 19% of the variance was accounted for in reading recognition, reading comprehension, and mathematics, respectively. Thus, the results indicated that both verbal STM and WM contribute unique variance to achievement in children and adults with learning disabilities.

For the sample without learning disabilities, the only significant predictor of reading recognition was prospective verbal WM, R^2 = .05, $F(1,84) = 4.18$, $p < .05$. Significant predictors of reading comprehension were prospective verbal WM, R^2 = .12, $F(1,84) = 11.32$, $p < .01$. Additional significant variance was added to the model with verbal STM scores, increment in R^2 = .07, $F(1,83) = 7.09$, $p < .01$; and visual STM scores, increment in R^2 = .06, $F(1,82) = 5.96$, $p < .01$. Significant predictors of mathematics were prospective verbal WM, R^2 = .10, $F(1,84) = 9.54$, $p < .01$; and prospective visual–spatial WM, increment in R^2 = .05, $F(1,83) = 5.19$, $p < .05$. No other variables predicted the criterion measures. Approximately 5%, 24%, and 16% of the variance was accounted for in reading recognition, reading comprehension, and mathematics, respectively. Thus, the results indicated that verbal WM contributed the highest variance to the three achievement measures, whereas the contribution of verbal STM was isolated to reading comprehension.

It could be argued that when vocabulary is not partialed out in the analysis, the verbal and visual–spatial measures share similar variance. Furthermore, except for the sample with learning disabilities, the previous factor analysis did not support the notion that verbal and visual–spatial measures reflected independent constructs. Thus, it was necessary to analyze the relative contribution of STM and WM when vocabulary and modality were not partialed out in the analysis. As shown in Table 6, composite STM and WM scores were entered into a stepwise regression analysis. The regression procedure allowed each measure to serve as the first predictor of achievement. Thus, the relative contribution of each remaining measure to achievement can be compared. The orderings are shown in Table 6. Because of the number of analyses, results related to only three criterion variables are shown.

Of particular interest was whether STM measures contributed unique variance to achievement in children and adults with learning disabilities, beyond what was contributed by WM. As shown in Table 6, regardless of the order, STM did not enter significantly into the equation when predicting reading recognition. The results indicate that WM makes a significant contribution to reading recognition, but only when entered into the equation first.

For reading comprehension, WM again played an important role, but only when entered into the equation first. This measure alone accounted for 10% of the variance, whereas STM contributed 10% of the variance when entered second. Short-term memory alone accounted for 17% of the variance when entered first. For mathematics, when WM was selected first, 14% of the variance was accounted for, whereas STM added 8%. Entering STM first accounted for 16% of the variance, and WM added 6%.

Table 6 also shows the stepwise regression for children and adults without learning disabilities. Compared with the small contribution of WM (5%) to recognition performance for children and adults with learning disabilities, WM contributed 13% of the variance to recognition performance of the sample without learning disabilities. Short-term memory made no important contribution to reading recognition. For reading comprehension, when WM was entered into the equation first, 16% of the variance was accounted for, and 13% when entered second. Short-term memory contributed no significant variance to reading comprehension. Working memory was also an important predictor of mathematics, accounting for 18% of the variance when entered into the equation first. Short-term memory accounted for 11% of the variance when entered into the equation first and 5% when entered second.

In sum, the results indicate that WM and STM contribute unique variance to achievement. The majority of the contribution for both measures is from verbal rather than visual-spatial processing. For children and adults without learning disabilities, WM yields higher R^2 than STM across achievement measures. For children and adults with learning disabilities, both WM and STM are important predictors of reading comprehension and mathematics, whereas WM makes the most

TABLE 6
Stepwise Regression with Three Achievement Measures as Criterion

Order of entry	Proportion of variance accounted for		R^2		F	
	NLD	LD	NLD	LD	NLD	LD
Reading recognition (WRAT-R)						
STM	.04	.03	–		*ns*	*ns*
WM	.10	.00	.14	.03	9.86**	*ns*
WM	.13	.05			13.18***	3.70*
STM	.00	.00	.13	.05	*ns*	*ns*
Reading comprehension (PIAT-R)						
STM	.03	.17	–		*ns*	15.18***
WM	.13	.03	.16	.20	13.84**	*ns*
WM	.16	.10			16.85**	8.97**
STM	.00	.10	.16	.20	*ns*	9.10**
Mathematics (WRAT-R)						
STM	.11	.16			10.997**	14.30***
WM	.09	.06	.20	.22	9.49*	5.12*
WM	.18	.14			15.69**	11.91**
STM	.05	.08	.21	.22	5.13*	7.36**

Note. WRAT-R = Wide Range Achievement Test–Revised; PIAT-R = Peabody Individual Achievement Test–Revised; STM = short-term memory; WM = working memory. NLD = nonlearning disabled; LD = with learning disabilities.
*$p < .05$. **$p < .01$. ***$p < .001$.

important contribution to reading recognition.

Discussion

This study represents part of an ongoing attempt to determine major cognitive predictors of reading problems in children and adults with learning disabilities. Overall, the present findings suggest that WM, rather than STM, made the most important contribution to reading recognition in the groups with and without learning disabilities. The results also suggest that verbal STM contributed unique variance to reading comprehension in the sample with learning disabilities, whereas STM did not contribute significant variance to reading comprehension in the sample without learning disabilities. Given these findings, the present study makes two important contributions to the existing literature.

First, WM and STM are independent constructs. Although researchers in the area of learning disabilities view the processes related to STM and WM as interchangeable (e.g., Jorm, 1983), the present study, along with other studies outside the domain of reading, suggests that processes related to STM and WM do not overlap but operate independently of each other (e.g., Brainerd & Kingma, 1985; Brainerd & Reyna, 1988; Cantor et al., 1991; Klapp et al., 1983). The prevailing opinion in the learning disabilities literature is that STM tasks are a proper subset of the processes of which WM is capable. In contrast to the opinion that WM and STM are interconnected, the present analysis suggests that WM does not share a common factor with STM. This finding is consistent with other experimental work (e.g., Brainerd & Kingma, 1985; Cantor et al., 1991); the implication is that children and adults with learning disabilities may suffer WM problems independent of problems in STM.

Second, the findings suggest that an isolated focus on STM may tell us little about predicting reading recognition for children and adults with learning disabilities. The results indicated that the best predictor of ability-group classification for children and adults selected primarily on reading recognition criteria is WM, not STM. No doubt, as suggested by Dempster (1985), low correlations between STM and achievement result from a restricted range of ability scores (e.g., Crawford & Stankov, 1983), as well as a preponderance of high ability scores (e.g., Daneman & Carpenter, 1980; Jackson & Myers, 1982). Thus, this author thought it important to determine whether correlations between reading recognition and short-term memory are more substantial when an array of measures is used across a wide range of age. The general finding was that for students with learning disabilities who have problems in reading recognition, WM was the best, although a weak, predictor. This pattern was noted for the PIAT-R as well as the WRAT-R measures (see Table 4). When focusing on reading comprehension and mathematics, however, a different set of results occurs. Both WM and STM contributed unique variance to performance. Although it has been established in the general literature that STM is not as critical to reading comprehension as WM is with nondisabled readers (e.g., Daneman, 1987), the present study suggests that for deficient readers, both STM and WM contribute to reading comprehension performance. Such a finding qualifies bottom-up models as explanations for the reading comprehension and mathematical difficulties of students with learning disabilities by suggesting that if lower-order processes, as reflected in STM measures, have an influence on high-order processing, their effects may occur independently of WM.

If WM deficits in children and adults with learning disabilities in the present study reflect problems in executive processing, at least in the verbal domain, then the present results are difficult to reconcile with the notion that reading problems are primarily due to verbal processes captured on STM measures. Baddeley (Baddeley, 1986; Baddeley & Hitch, 1974) ascribed the active manipulation aspects of WM to the central executive. Thus, one is tempted to suggest from the results in the present study that students with learning disabilities have some type of deficit related to an isolated storage system that monitors verbal resources. Unfortunately, there is increasing skepticism about the usefulness of the resource concept related to executive processing (e.g., Stanovich, 1990), and recent data restrict the generalizability of that interpretation (Brainerd & Reyna, 1989). An alternative is to emphasize the lack of flexibility in coordinating several types of verbal memory stores rather than an output problem from a particular store. In this view, the processing systems of subjects with and without learning disabilities may or may not have the same WM capacity, but a very important aspect of learning disabilities is coordinating and/or compensating for the verbal processes they have (see Swanson, 1989, 1993a). This option differs from the processing-versus-storage issue by emphasizing the coordination of processes. This emphasis may be useful in resolving apparently conflicting results of memory process intervention, some of which eliminate ability-group differences (e.g., Dallego & Moely, 1980), and others of which do not (e.g., Gelzheiser, 1984; Wong, 1978). Perhaps tasks that rely on a passive storage system (such as reflected in the STM measures in this study, i.e., digit span) will not always show differences between groups on verbal tasks, but tasks that actively pair verbal process and storage demands (as reflected in WM measures) will.

Given the extensive literature linking STM to reading disabilities, especially at the word-recognition level (e.g., Jorm, 1983; Shankweiler & Crain, 1986; Vellutino, 1979), some further explanation of the importance of STM to our understanding of learning disabilities must be considered. No doubt, the importance of STM to reading disabilities reflects the fact that STM relies on an articulatory code (Cohen & Heath, 1990; Salame & Baddeley, 1982)—a code critical to reading acquisition (Baddeley et al., 1982; Bisiacchi et al., 1989)—whereas WM tasks are assumed to tap executive functioning (Daneman, 1987; Engle, Nations, & Cantor, 1990)—a skill critical to high-order processing, such as reading comprehension and mathematics (e.g., Engle et al., 1990). However, recent results reported by Cantor et al. (1991) may further clarify the role of STM in high-order tasks, such as reading comprehension. Their study assessed the relationship between complex span measures of WM, measures of STM, and comprehension as measured by the verbal SAT. Their results show that two distinct factors, STM and WM, contribute significant variance to comprehension. In a more recent study, Engle et al. (1992) argued that STM is important to reading comprehension that involves surface coding (e.g., the recall of words in a phrase, i.e., literal comprehension), whereas WM is important for grasping the complexities in reading comprehension. Because the sample with learning disabilities may have relied more on surface coding than did the nondisabled group when responding to the comprehension questions from the PIAT-R, it is possible that STM predicted the performance by the children and adults. Thus, it may be that because students with learning disabilities suffer surface-coding difficulties, the correlation between STM and comprehension is accented. In contrast, students without learning disabilities can easily access certain surface codes, thereby weakening the correlations between STM and high-order processing on such measures of reading comprehension, as well as of mathematics. No doubt, further research is necessary to address these assumptions.

In general, the present results are instructive with respect to the contribution of STM and WM to the academic achievement of children and adults with learning disabilities. Because children and adults with learning disabilities experience verbal WM problems that cut across academic domains, their problems in processing information may be functionally related to higher-order processes, such as central executive processing. The results also suggest that although STM and WM make independent contributions to some areas of academic performance, the effectiveness of STM in predicting reading comprehension and mathematics ability is enhanced in the sample with learning disabilities.

ABOUT THE AUTHOR

H. Lee Swanson *received his PhD from the University of New Mexico. His interests are information-processing theory, intelligence, and attention. Address: H. Lee Swanson, School of Education, University of California, Riverside, CA 92521.*

AUTHOR'S NOTE

This research was partially funded by an SSHRC grant, University of British Columbia, and Peloy Endowment Funds from the University of California at Riverside. Special thanks are given to the interns at the Educational Clinic, University of British Columbia, for data collection. Results from this study were presented at the International Academy for Research in Learning Disabilities Conference, Cincinnati, OH, 1991. The author is thankful to two anonymous reviewers of an earlier version of this article.

NOTE

Everyday examples of WM tasks would thus include holding a person's address in mind while listening to instructions about how to get there, or perhaps listening to the sequence of events in a story while trying to understand what the story means. Described in this way, WM differs from the concept of short-term memory that is typically used to describe situations in which small amounts of material are held passively (e.g., digit- or word-span tasks) and then reproduced in an untransformed fashion (Brainerd & Kingma, 1985; Just & Carpenter, 1992).

REFERENCES

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

Baddeley, A. D. (1986). *Working memory.* London: Oxford University Press.

Baddeley, A. D., Ellis, N., Miles, T. R., & Lewis, V. J. (1982). Developmental and acquired dyslexia: A comparison. *Cognition, 11,* 185–199.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Baddeley, A. D., Logie, R., & Nimmo-Smith, I. (1985). Components of fluent reading. *Journal of Memory and Language, 24,* 119–131.

Baddeley, A. D., & Wilkins, A. (1985). Taking memory out of the laboratory. In J. E. Harris & P. E. Morris (Eds.), *Everyday memory actions and absentmindedness* (pp. 1–19). San Diego: Academic Press.

Bauer, R. H. (1979). Memory processes in children with learning disabilities. *Journal of Experimental Child Psychology, 24,* 415–430.

Bentler, P. M., & Bonett, D. (1980). Significance tests and goodness of fit in the analysis of covariance structures. *Psychological Bulletin, 88,* 588–606.

Bisiacchi, P. S., Cipolotti, L., & Denes, G. (1989). Impairment in processing meaningless verbal material in several modalities: The relationship between short-term memory and phonological skills. *The Quarterly Journal of Experimental Psychology, 41A,* 293–319.

Brainerd, C. J., & Kingma, J. (1985). On the independence of short-term memory and working memory in cognitive development. *Cognitive Psychology, 17,* 210–247.

Brainerd, C. J., & Reyna, V. F. (1988). Generic resources, reconstructive processing and children's mental arithmetic. *Developmental Psychology, 24,* 324–334.

Brainerd, C. J., & Reyna, V. F. (1989). Output-interference theory of dual-task deficits in memory development. *Journal of Experimental Child Psychology, 47,* 1–18.

Cantor, J., Engle, R. W., & Hamilton, G. (1991). Short-term memory, working memory, and verbal abilities: How do they relate? *Intelligence, 15,* 229–246.

Carlson, R. A., Khoo, B., Yaure, R. G., & Schneider, W. (1990). Acquisition of problem-solving skill: Levels of organization and use of working memory. *Journal of Experimental Psychology: General, 119,* 193–214.

Chiang, A., & Atkinson, R. C. (1976). Individual differences and interrelationships among a select set of cognitive skills. *Memory and Cognition, 4,* 661–672.

Cohen, R. L. (1981). Short-term memory deficits in reading disabled children in the absence of opportunity for rehearsal strategies. *Intelligence, 5,* 69–76.

Cohen, R. L., & Heath, M. (1990). The development of serial short-term memory and the articulatory loop hypothesis. *Intelligence, 14,* 151–171.

Crawford, J., & Stankov, L. (1983). Fluid and crystallized intelligence and primacy/recency components of short-term memory. *Intelligence, 7,* 227–252.

Crowder, R. G. (1976). *Principles of learning and memory.* Hillsdale, NJ: Erlbaum.

Dallego, M. L., & Moely, B. E. (1980). Free recall in boys of normal and poor reading levels as a function of task manipulation. *Journal of Experimental Child Psychology, 30,* 62–78.

Daneman, M. (1984). Why some people are better readers than others: A process and storage account. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 367-384). Hillsdale, NJ: Erlbaum.

Daneman, M. (1987). Reading and working memory. In J. R. Beech & A. M. Colley (Eds.), *Cognitive approaches to reading* (pp. 57-86). New York: Wiley.

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

Daneman, M., & Carpenter, P. A. (1983). Individual differences in integrating information between and within sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 561–584.

Daneman, M., & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language, 25,* 1–18.

Dempster, F. N. (1985). Short-term memory development in childhood and adolescence. In C. J. Brainerd & M. Pressley (Eds.), *Basic processes in memory* (pp. 75-101). New York: Springer-Verlag.

Dixon, P., LeFevre, J., & Twilley, L. C. (1988). Word knowledge and working memory as predictors of reading skill. *Journal of Educational Psychology, 80,* 465–472.

Dunn, L. (1981). *Peabody picture vocabulary test-Revised.* Circle Pines, MN: American Guidance Service.

Dunn, L., & Markwardt, F. C. (1988). *Peabody individual achievement test-Revised.* Circle Pines, MN: American Guidance Service.

Ellis, N., & Large, B. (1987). The development of reading: As you seek so shall you find. *British Journal of Psychology, 78,* 1–28.

Engle, R., Cantor, J., & Carullo, J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 972–992.

Engle, R. W., Nations, J., & Cantor, J. (1990). Is working memory capacity just another name for word knowledge? *Journal of Educational Psychology, 82,* 799–804.

Federal Register, 42, (No. 250), Thursday, December 29, 1977.

Felton, R. H., & Brown, I. (1991). Neuropsychological prediction of reading disabilities. In J. Obrzut & G. Hynd (Eds.), *Neuropsychological foundations of learning disabilities* (pp. 387–410). San Diego, CA: Academic Press.

Fletcher, J. M. (1985). Memory for verbal and nonverbal stimuli in learning disability subgroups: Analyses by selective reminding. *Journal of Experimental Child Psychology, 40,* 244–259.

Gelzheiser, L. (1984). Generalization from categorical memory tasks to prose by learning disabled adolescents. *Journal of Educational Psychology, 76,* 1128–1138.

Gieselman, R. E., Woodward, J. A., & Beatty, J. (1982). Individual differences in verbal performance: A test of alternative information processing models. *Journal of Experimental Psychology: General, 111,* 109–134.

Hammill, D. (1985). *Detroit test of learning aptitude, second edition.* Austin, TX: PRO-ED.

Hulme, C. (1992). *Working memory and severe learning difficulties—Essays in cognitive psychology.* East Sussex, United Kingdom: Erlbaum.

Jackson, N. E., & Myers, M. G. (1982). Letter naming time, digit span, and precocious reading achievement. *Intelligence, 6,* 311-329.

Jastak, S., & Wilkinson, G. S. (1984). *Wide range achievement test-Revised.* Wilmington, DE: Jastak Associates.

Joreskog, K. G., & Sorbom, D. (1984). *LISREL VI: Analysis of linear structural relationships by the method of maximum likelihood.* Mooresville, IN: Scientific Software.

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. *British Journal of Psychology, 78,* 311–342.

Just, M., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychology Review, 99,* 122–149.

Kaufman, A., & Kaufman, N. L. (1983). *Kaufman assessment battery for children (K-ABC) interpretive manual.* Circle Pines, MN: American Guidance Service.

Klapp, S. T., Marshburn, E. A., & Lester, P. T. (1983). Short-term memory does not involve the "working memory" of intellectual processing: The demise of a common assumption. *Journal of Experimental Psychology: General, 112,* 240-264.

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

Maracuilo, L., & Levin, J. R. (1983). *Multivariate statistics in the social sciences.* Monterey, CA: Brooks/Cole.

Marsh, H. W., Balla, J. R., & McDonald, R. P. (1988). Goodness-of-fit indexes in confirmatory factor analysis: The effect of sample size. *Psychological Bulletin, 103,* 391–410.

Masson, M. E. J., & Miller, J. A. (1983). Working memory and individual differences in comprehension and memory of text. *Journal of Educational Psychology, 75,* 214–219.

Mishra, S. P., Shitala, P., Ferguson, B. A., & King, P. V. (1985). Research with the Wechsler Digit Span subtest: Implications for assessment. *School Psychology Review, 14,* 37–47.

Payne, M. C., & Holzman, T. G. (1983). Auditory short-term memory and digit span: Normal versus poor readers. *Journal of Educational Psychology, 75,* 424–430.

Perfetti, C. A., & Lesgold, A. N. (1977). Discourse comprehension and sources of individual differences. In M. Just & P. Carpenter (Eds.), *Cognitive processes in comprehension.* Hillsdale, NJ: Erlbaum.

Raven, J. C., Court, J. H., & Raven, J. (1986). *Manual for Raven's progressive matrices and vocabulary scales. U.S. norms.* London: Lewis.

Salame, P., & Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior, 21,* 150-164.

Salthouse, T. (1990). Working memory as a processing resource in cognitive aging. *Developmental Review, 10,* 101–124.

Schneider, W., & Detweiler, M. (1987). A connectionist/control architecture for working memory. In G. H. Bower (Ed.), *The psychology of learning and motivations* (Vol. 21, pp. 53–119). New York: Academic Press.

Shankweiler, D., & Crain, S. (1986). Language mechanisms and reading disorder. *Cognition, 24,* 139-168.

Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., & Fischer, F. W. (1979). The speech code and learning to read. *Journal of Experimental Psychology: Learning, Memory & Cognition, 5,* 531-545.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 120-190.

Siegel, L. S., & Linder, A. (1984). Short-term memory processes in children with reading and arithmetic disabilities. *Developmental Psychology, 20,* 200-207.

Siegel, L. S., & Ryan, E. B. (1989). The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development, 60,* 973-980.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21,* 360-406.

Stanovich, K. E. (1990). Concepts in developmental theories of reading skill: Cognitive resources, automaticity, and modularity. *Developmental Review, 10,* 72-100.

Swanson, H. L. (1983). A study of nonstrategic linguistic coding on visual recall of learning disabled and nondisabled readers. *Journal of Learning Disabilities, 16,* 209-216.

Swanson, H. L. (1989). The effects of central processing strategies on learning disabled, mildly retarded, average, and gifted children's elaborative encoding abilities. *Journal of Experimental Child Psychology, 47,* 370-397.

Swanson, H. L. (1992). The modifiability and generality of working memory in skilled and less-skilled readers. *Journal of Educational Psychology, 84,* 473-488.

Swanson, H. L. (1993a). Executive processing in learning disabled readers. *Intelligence.*

Swanson, H. L. (1993b). Working memory in learning disability subgroups. *Journal of Experimental Child Psychology, 56,* 87-114.

Swanson, H. L. (in press). *Mental processing potential test.* Austin, TX: PRO-ED.

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

Swanson, H. L., & Cooney, J. B. (1991). Memory and learning disabilities. In B. Y. L. Wong (Ed.), *Learning about learning disabilities* (pp. 104-122). San Diego, CA: Academic Press.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization and memory* (pp. 381-450). New York: Academic Press.

Tulving, E. (1983). *Elements of episodic memory.* Oxford, England: Oxford University Press.

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

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

Wong, B. Y. L. (1978). The effects of directive cues on the organization of memory and recall in good and poor readers. *Journal of Educational Research, 72,* 32-38.