THE RELATIONSHIP OF AUTOMATICITY, METACOGNITION, AND WORKING MEMORY IN NORMAL AND LEARNING DISABLED READERS

by

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ABSTRACT

In this study 40 disabled and 40 non-disabled readers were selected in equal numbers from grade three and grade six and compared on 26 variables which have been shown to play significant roles in skilled reading. The variables were grouped into three processing tasks: automaticity, metacognition and working memory. One purpose of this study was to compare learning disabled and non-disabled readers ' performance on these tasks. The general findings were that the two groups (both age and ability) differed significantly on all three processing tasks. It was also the purpose of this study to compare the intercorrelational patterns of learning disabled and non-disabled youngsters on these three processes. In interpreting this relationship, two competing frameworks were compared: the modularity and the general resource models. The results indicate a significant relationship between automaticity, working memory and metacognition for the total sample and both the LD and non-disabled group. The intercorrelational pattern was qualified, however, when vocabulary was partialled out in the analysis. Although strong intercorrelation patterns occurred for the total sample the relationship between working memory and automaticity was weakened within ability groups. Both working memory and automaticity maintained a significant correlation with reading. Results provide support for the notion that a general working memory is related to reading ability, as well as the fact that automatic processes operate as encapsulated operations only when word knowledge is partialled out in the analysis. Overall, the results suggest that a general resource system plays a major role in accounting for ability group differences.

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DEDICATION

This work is dedicated to my father, Edward Benson.

I. INTRODUCTION

A. FUNCTIONAL WORKING MEMORY

The study of human memory has a notable place in empirical research. However, the concept of *working memory* is a relatively new construct which is thought to have important implications for the understanding of individual differences in achievement. Contemporary theories have indicated that working memory has a central role to play in cognitive development (Case, 1978), text processing (Kintsch & van Dijk, 1978), and reading (Perfetti, 1985; Perfetti & Lesgold, 1977). The present study is specifically interested in working memory and its relationship to reading achievement in non-disabled and disabled readers.

Research to date indicates that working memory plays a pivotal role in differences found in reading ability (Daneman & Carpenter, 1980; Kintsch & van Dijk, 1978; Masson & Miller, 1983; Swanson, Cochran, & Ewers, 1990; Turner & Engle, 1989). Further, current studies using dual tasks to tap the central processing component of working memory indicate that learning disabled children suffer from a central processing deficit of working memory (Swanson, 1989; Swanson, Cochran, & Ewers, 1989, 1990). LD children fail to effectively prioritize items in memory and show "retarded-like behaviour" in their ability to discriminate items in memory (Swanson, 1989). These findings are in contrast to previous research regarding memory and reading skill which found weak or nonexistent correlations between reading and memory measures (e.g., Dempster, 1985). Because of these conflicting results, it is important to clarify what is meant by working memory and to distinguish it from previous memory concepts.

1. What is Working Memory?

Early theories had conceptualized memory as a fixed number of slots (see Turner & Engle, 1989, for review). However, research using the traditional digit or word span test to measure this short term memory capacity resulted in low or insignificant correlations with standardized reading measures (see Jorm, 1983, for review).

Baddeley and Hitch (1974) felt that the problem lay in the emphasis on the storage component of memory. They argued that a processing component as well as a storage function was present. They developed a model of memory using the name working memory which they felt better reflected the processing as well as storage functions. Their model conceptualized working memory as having three structural components through which information is processed: (a) a central executive, (b) an articulatory loop, and (c) a visuo-spatial scratch pad. The visuo-spatial scratch pad is used for the temporary storage and manipulation of visuo-spatial information while the articulatory loop is used for the storage and manipulation of speech based material. The primary function of the central executive is to control, monitor, and organize, whereas the principle role of the subsystems is to store information. According to Swanson et al. (1990), an underlying assumption of this model is that the peripheral systems occupy "separate though interrelated capacity pools" (p. 60). The articulatory loop and visuo-spatial scratch pad are maintenance systems controlled by the central executive. The central executive is seen as a flexible work space with limited capacity. Part of this limited capacity is used for processing incoming information with the remainder used for storage of the products resulting from that processing. This model of working memory prompted a great deal of empirical research because of its capacity for generating testable hypotheses.

Among the more notable research using this model of working memory was the work of Daneman and Carpenter (1980). In their research they demonstrated the importance of the limited capacity of working memory in reading comprehension--specifically the trade-off between processing and storage functions. They hypothesized that a poor reader's processes may be inefficient, reducing the amount of additional information that can be maintained in working memory. They developed a Sentence Span measure to test this hypothesis. The Sentence Span measure resulted in significant correlations with reading scores. In this seminal work by Daneman and Carpenter, subjects were presented with a series of sentences which they had to read, while at the same time trying to retain the last word of each sentence. Working memory performance was measured as the maximum number of sentences processed (which was tested by asking a comprehension question regarding the material read) while correctly recalling the last word. This Sentence Span test is thought to tap both the processing and storage functions of working memory capacity. The processing component is the sentence reading task with the comprehension question and the storage component is the final word recall requirement.

Daneman and Carpenter extended their findings by comparing the relationship of the Sentence Span score with reading in oral reading situations, in silent reading situations, and in listening situations. The oral reading span score, silent reading span score, and listening span score resulted in correlations of .81, .74, and .67 respectively, with factual comprehension questions.

The results of this research using the span measure were important for two reasons. First, it demonstrated the difference in the relationship between conventional STM and reading comprehension as compared with the relationship between working memory and reading comprehension. Second, the research indicated that working memory may be an important predictor of individual differences in reading skill.

2. Is Working Memory Task Dependent?

Daneman and Carpenter (1980, 1983) argued, based on their work with the Sentence Span task, that the interrelationship between reading and working memory is high because the working memory task requires the subject to use the same reading-specific processes (linguistic processes) that are contained in the criterion measure. If the poor reader does not have efficient reading skills his working memory capacity is overloaded and therefore he has fewer resources available for storing the products of reading. They conclude that efficiency of processes related to reading, not memory capacity, account for the differences in working memory and its strong relationship to reading skill. Working memory's relationship to reading is, therefore, task dependent.

An alternative hypothesis to the task dependent efficiency theory is that the source of individual differences in reading resides in differences in the overall structural capacity of working memory. That is, poor readers have weaker working memories than skilled readers, not as a consequence of poor reading skills, but because they have less working memory capacity available for performing reading and non-reading tasks. To test this theory, Turner and Engle (1989) designed a study using four working memory tasks: sentence-word, sentence-digit, operations-word, and operations-digit. All four working memory subtests were significantly correlated with a standardized reading measure. Turner and Engle interpreted their results as providing tentative support for the theory that working memory capacity may be task independent. They argued that people who are good readers have larger working memory capacity independent of the task being performed.

Further support for the task independent theory comes from the work of Engle, Cantor, and Carullo (1992). In this study the authors tested four hypotheses in regard to differences in working memory and comprehension: a general processing hypothesis, a task specific hypothesis, a general resource capacity hypothesis, and a strategic allocation hypothesis. By using working memory tasks similar to those of Turner and Engle (1989) and partialling out the processing component, they were able to discount the general processing theory. Next they reasoned that if there was a trade-off between processing and storage (strategic allocation), the increases associated with decreased performance on the processing component would disappear when the processing component was partialled out. This was not the case. These results supported the general resource capacity theory. This theory states that people who are good readers are so because they have larger working memory capacities, independent of the specific task being performed.

3. Working Memory in the Present Study

It is working memory's relationship to reading that is the focus of this paper. Specifically the paper is concerned with processing within this limited capacity system in terms of the information processing theories of reading that focus on automaticity (Gough, 1972; Kintsch & van Dijk, 1978; LaBerge & Samuels, 1974; Perfetti, 1985; Schwartz, 1984; Stanovich, 1980) and reading theories that focus on the controlled higher order process of metacognition (Baker & Brown, 1984). The research within these theories indicates that skill in automaticity of lower order skill and skill in metacognitive tasks are related to skilled reading. The question arises then, is there a common underlying central processing component in all three that would account for their relationship to reading or do the three act independently in their relationship to reading? The former concept is found in the *resource capacity model* (Engle et al., 1992; Walczyk & Raska, 1992) and the latter in *modularity model* proposed by Stanovich (1990). The resource capacity model indicates that good readers have larger working memory capacities, independent of the specific task being performed. Implicit in this theory is the concept of a central executive responsible for the control and organizing of process. If both metacognition and automaticity are related to measures of working memory, and measures of working memory tap this central executive, this would support the general resource capacity model. Proponents of the modularity theory, on the other hand, argue that automaticity of lower order skills and metacognition are related to reading ability in and of themselves, not because of any central executive control. The processes of automaticity of lower order skills and metacognition are independent of an overriding control system. That is, automaticity of lower order skills would only be significantly related to working memory when they share a common reading-related component. Support for this theory would be found if measures of automaticity and metacognition were not significantly related to measures of working memory that tap the central executive component.

A secondary focus of the paper is to address the question of whether it is necessary for lower order reading skills to be efficient (automatized) in order that sufficient space be available in working memory for comprehension to occur. Walczyk and Raska (1992) has indicated that if there is a positive correlation between measures of working memory, metacognition, and automaticity, this would indicate that automaticity of lower order skills is necessary for skilled reading. If there is a positive correlation between metacognition and working memory but not with automaticity, the opposite would be the case. This study will, in part, address Walczyk 's argument.

In order to explore these questions, it is necessary to look at the research regarding automaticity of lower order reading skills and the research regarding metacognitive skills in order to discover what is known about these factors and their relationship to working memory.

B. AUTOMATICITY

According to LaBerge and Samuels (1974), a major factor in reading difficulty is the lack of automaticity in decoding which overloads the attentional system and leads to the use of small, meaningless visual processing units, such as individual letters. A heavy demand is thereby placed on working memory and comprehension suffers.

Evidence that poor readers are less likely to use automatic processes than good readers also comes from experiments reported by Fredericksen (1981). He found that poor readers showed a higher correlation between reading times for high and low frequency words than good readers, and that a strongly constraining sentence context reduced reading time (as compared with reading time for words in isolation) for poor readers. Fredericksen's interpretation of these findings was that good readers decode words automatically and are less affected by context than poor readers. Schwartz (1984), after reviewing the literature on individual differences in reading ability, concludes that highly practised automated processes are the best place to look for these differences. He states that the degree to which decoding skills have become automatic is reflected in better reading scores because automatic decoding frees cognitive capacity for comprehension processes.

Although agreeing with the basic concept of automaticity of reading subskills resulting in better standardized reading scores, Perfetti (1985) prefers the word efficient to automatic. He feels the usual understanding of automatic implies a process requiring the expenditure of no resources. He maintains that a task meeting this definition, particularly in the process of reading, is difficult to isolate. Perfetti's theory of verbal efficiency views working memory as a limited capacity processing system that is constrained by the number of memory elements that can be simultaneously activated. The outcome of reading is limited by the efficient operation of subcomponent processes--processes such as lexical access. High efficiency lexical access and other low level skills leave resources free for higher level reading skills such as encoding propositions, making inferences, and interpretive and critical comprehension.

Thus, current models of information processing in reading imply that skilled reading involves the comparatively smooth execution of reading subcomponents making minimal demands on a limited working memory capacity. As lower level skills become automated, higher level skills can employ the limited capacity of working memory to make comprehension easier.

Although many reading models make reference to metacognitive skills in the reading process, they do not explore its interrelationship with low level skills. This stems from the fact that many of the information processing models have word recognition as their focus (Gough, 1972; LaBerge & Samuels, 1974; Stanovich 1980). Although information processing models such as that of Stanovich (1980) recognize the interactive compensatory processes of reading, whereby a deficit in any particular process will result in a greater reliance on other knowledge sources, regardless of their level in the processing hierarchy, the model appears to confine this compensation, for the most part, to the word recognition level.

Perfetti (1985), likewise, acknowledges that his verbal efficiency theory does not imply that the reader is totally "at the mercy of low level processing skills" (p. 119). He assumes that the component processes of reading are interactive and that there are procedures that can be applied to compensate for inefficiency of low level processes. For example, inefficient lexical access can be overcome, to some extent, by schema-based processes based on prior knowledge. However, he fails to explore the relationship between low level processing and metacognitive strategies. He concludes that the construction of a quality text model depends upon the efficiency of low level processes freeing working memory resources for higher level text comprehension.

Few would question the importance of low level reading skills. In fact, decoding is probably the most studied topic in reading (Spiro & Myers, 1984). But much of the current research also indicates the importance of metacognitive skills as the following look at the research will indicate.

C. METACOGNITION

Current focus on planning and monitoring activities (conscious, strategic processes) that fall under the heading metacognitive skills are acknowledged as important in the reading process (Bransford & Johnson, 1972; Markman, 1979; Nicholson & Imlach, 1981; Stein et al., 1982). Metacognitive skills involve awareness, monitoring, and deployment of compensating strategies (Baker & Brown, 1984). Whimbey's (1975) characterization of a good reader captures the essence of comprehension monitoring in the following:

> A good reader proceeds smoothly and quickly as long as his understanding of the material is complete. But as soon as he senses that he has missed an idea, that the track has been lost he brings smooth progress to a grinding halt. Advancing more slowly he seeks clarification in the subsequent material, examining it for the light it can throw on the earlier trouble spot. If still dissatisfied with his grasp he returns to the point where the difficulty began and rereads the section more carefully. He probes and analyzes phrases and sentences. (p.91).

Research supports Whimbey's characterization. For example, after realizing that one does not understand, the reader may store the confusion in memory, hoping the author will offer clarification (Anderson, 1980). The reader may reread, jump ahead, or consult a dictionary (Alessi, Anderson, & Goetz, 1979). The remedial action taken is largely dependent upon the purpose of reading (Alessi et al., 1979). Further, the research indicates that metacognitive ability is often very limited in young children but increases with age (Brown, 1978; Markman, 1979).

In summary, although both automaticity of low order reading skills and metacognition have been shown to affect reading ability, little systematic exploration has been done on the relationship between the two in light of the research on working memory. We need to know if there is a common central executive which controls both automaticity of lower order skills and metacognition, or whether metacognition and automaticity act independently of a central executive in their relationship to reading. Further, in looking at the relationship of automaticity, metacognition, and working memory, the question of the necessity of automatic lower order skills to free space in working memory for comprehension can be addressed. Perfetti states that as low level skills become automatic or efficient, working memory capacity is freed for metacognition to work. However, Spiro and Myers (1984) point out that things are rarely as simple as they seem. It may be that even the obvious point about excesses in the effort of one process detracting from another need not hold. In some cases it might be that more effort in one process (e.g. schema selection based on prior knowledge) reduces the effort required by others. We need to know more about when process interaction takes the form of compensatory facilitation and when there is a unidirectional bottleneck with little interaction between high and low order reading skills.

D. PROBLEM

Research, then, has indicated that working memory is an important determinant of differences found in reading ability. Working memory is conceptualized as a limited capacity system. Studies using dual tasks to tap the central executive component of working memory have shown the LD children suffer from central processing difficulties. Automaticity in lower level reading skills and metacognitive ability have also been shown to influence reading ability. However, we do not have a clear understanding of the relationship of automaticity of lower order skills and metacognitive skills, within the limited capacity of working memory. This relationship can be explored in the light of two models: the modularity model and the general resource capacity model.

At first glance, these two models may not appear to be juxtaposed and, therefore, to interpret the results of a study of the relationship of working memory, automaticity of lower order skills and metacognition as support for one model over the other would be problematic. However, the present study conceptualizes modularity and general resource capacity as they are currently presented in the reading and school psychology literature. The following are descriptions of the two models.

1. General resource capacity model

According to this model there is a limited pool of general cognitive resources that can be dynamically allocated to handle the most compelling need of the cognitive system (Walczyk, 1993). In this model a central executive is responsible for the efficient execution of processes within a limited capacity system. This model indicates that the reason a student shows good reading ability is because lower order skills, working memory and metacognition are all efficiently controlled by a central executive responsible for organizing and monitoring processing. If lower order reading skills are inefficient, limited resources are used up, and, thus, fewer resources are available for efficient reading. According to this view, a correlation between subcomponent efficiency and reading is expected (Walczyk, 1993).

Support for the general capacity theory in reading is found in the recent research of Wagner, Torgesen, Laughon, Simmons & Rashotte (1993). In this research the authors found, using phonological tasks, working memory tasks, isolated naming of digits tasks and serial naming of digits tasks, that phonological processing abilities were more highly correlated with general cognitive ability than previous reports would suggest. In this study intercorrelations between phonological process and general memory were found. The authors suggest that phonological skills do not appear to be encapsulated and do not operate separate from a general capacity system.

2. Modularity model

In 1983 Fodor, in a seminal work, presented a book which describes modular organization. In this book, Fodor proposed four properties of modules. Modules are: 1) encapsulated (which refers to systems that operate independent a central system), 2) are built to give fast processing of material, 3) are "hard-wired" (which refers to fact that they are built in biologically rather than assembled over time), and 4) are domain specific (which refers to that fact that information within a module or shared between modules has a common, specified theme). In the present study encapsulation is the primary focus because the notion of encapsulation has been found in the reading literature. In Fodor's description, encapsulation means that modules have only limited access to each other. Modules are not completely closed to one another, but the kind of material one module receives from another is strictly specified. Encapsulations serve to aid fast processing because the systems need only consider a fraction of the available information, in a specified way. Fodor's view of modularity does not rule out the role of central systems (which are unencapsulated), but he fails to explore how central processing may indirectly affect modular systems.

More recently Stanovich (1988) explored the modularity and central processing concept in reference to reading. Stanovich indicated that central cognitive processes are "precisely the wrong places" to look for the cause of reading disabilities (Stanovich, 1988, p. 212). He states that the best place to look for key processes to reading ability will be those areas that are "somewhat modular in (roughly) Fodor's sense".

(Stanovich, 1988, p.212). Although Stanovich acknowledges that Fodor's model of modularity includes subsystems that are fast, automatic, and information encapsulated, he further states that the important aspect is "encapsulation". Stanovich goes on to define encapsulation as processes that are autonomous and not under the control of a central structure.

In a recent article, Stanovich (1990) proposes several reasons to abandon the resource capacity model when looking for reasons for individual differences in reading ability. He indicates that the resource capacity model is not as empirically tractable as the encapsulation model. Moreover, he feels that the research literature has failed to show that the development of obligatory processing coincides with the development of capacity-free processing. He states that research in general capacity processing such as Daneman and Tardif's work (1987) has supported the notion of domain specificity. Therefore, he views information encapsulation as the way of the future in reading theory. "Information encapsulation (or functional autonomy or cognitive impenetrability) means that the operation of a module is not controlled by high order processes or supplemented by information from a knowledge structure not contained in the module itself" (p. 82). That is, automaticity of lower order skills acts on reading, independent of a higher order processing control. Likewise, the metacognitive strategies involved in reading are responsible for skilled reading because of their relationship to reading, not because of any central executive control.

Siegel (1989a) uses Stanovich's argument, in part, to advocate for the irrelevance of IQ testing in designating LD children. Her line of reasoning reveals the possible direction the acceptance of a "rough" modularity theory may take those working with and testing LD children. In addition to suggesting that we abandon the use of IQ test in defining and identifying learning disabilities, Siegel also implies that it may be fruitless to search for better measures of intelligence. Although one may or may not agree with the use of the WISC-R to measure general intellectual processing it may not be appropriate to eliminate the role of central processing in learning disabled youngsters.

Thus an investigation into the relationship between of lower order skills, metacognition, and working memory may shed light on these two models. We need to know if this relationship is unique in learning disabled children who it has been suggested have a central processing deficit in working memory (Swanson, 1989).

E. PURPOSE

The purpose of this paper, then, is to examine the relationship of automaticity of lower order processing skills which are thought to be modular, metacognition, and working memory in learning disabled readers. In interpreting this relationship, two frameworks are compared: the modularity and the general resource models. The relationship among the three processes is considered at two age levels.

F. RATIONALE

By measuring several lower order reading skills and several metacognitive reading skills as well as verbal and non-verbal working memory at two different ages, it may be possible to formulate a picture of the relationship between automaticity, metacognition, and working memory processes. Further, by sampling from the normal classroom as well as the learning disabled population, it will be possible to see if a unique relationship exists for the learning disabled population.

Support for the modularity model would be found if the three constructs were not significantly correlated. Support for the resource capacity model would be found if all three constructs were significantly correlated. Since the relationship may change developmentally and be unique for the learning disabled reader, this relationship will be looked at in the LD population as well as from a developmental perspective.

G. DEFINITION OF TERMS

Although the literature review will provide rationale for the definitions of terms used throughout the study, for the purposes of clarity and reference the following section of definitions of terms is offered:

1. Working Memory

Working memory is defined as the preservation of information while simultaneously processing the same or other information. It is distinguished from other forms of memory because it reflects both process and storage and plays an important role in many cognitive tasks.

2. Automaticity

Automaticity is defined as the speed and accuracy with which a component skill of reading is carried out. In this study the processes are lower order reading skills exclusively at the word level of processing.

3. Metacognition

Metacognition is defined as the knowledge about those processes in reading that the individual has control over, including the ability to reflect on the reading process, comprehension monitoring, and deployment of strategies to alleviate difficulties.

4. Lower Order Reading

Lower order processes are defined as those processes at the word level of reading which include phonological processing, orthographic processing, semantic processing, and word recognition. Phonological processing is further broken down into analysis, synthesis, lexical access, and coding at the word level. An example of the phonological processing, then, would be the ability to separate the "c" sound from the word cat (analysis), blend the sounds "c", "a", "t" to say cat (synthesis), rapidly accessing the word cat in the lexicon (lexical access), and being able to repeat the word cat (coding). It is these lower order reading skills that are thought to be modular.

H. SUMMARY

Research has shown that children who score higher on measures of working memory also score higher on standardized reading measures; children who score higher on measures of automaticity of lower order skills also score higher on standardized reading measures; and children who score higher on measures of metacognition also score higher on standardized reading measures. These research findings lead to the following questions. What is the pattern of relationship of the three constructs? Do working memory, automaticity of lower order skills, and metacognition share a common central system (as the theory of general resource capacity would indicate), or do some of these constructs, such as lower order phonological skills, operate independent of a general system (as the modularity theory would indicate)? The relationship between automaticity, metacognition, and working memory in reading needs to be more clearly articulated by measuring the three constructs and analyzing the relationship. By measuring working memory using several tasks which will tap the central executive component, a working memory construct can be formed. By measuring automaticity of lower order skills using several tasks which tap salient components of lower order processing, an automaticity construct can be formed. By measuring metacognition using several metacognitive tasks, a metacognitive construct can be formed. By looking at the relationship of these constructs, answers can be formulated to the question regarding their underlying relationship. If a significant relationship exists between the three constructs, this would support the general resource capacity theory. If no significant relationship is found between the three constructs, this would support the modularity theory. Since research has shown that there are developmental changes in the tasks that make up the constructs, the relationship should be looked at developmentally. Moreover, research has shown that LD children have a unique central processing component in working memory, so this relationship should be looked at in the LD group.

The relationship of the three constructs can also be looked at in terms of current literature regarding the necessity of automated lower order skills to free space in working memory for comprehension. Walczyk and Raska (1992) state that a positive relationship between metacognition, working memory, and automaticity lends support to the argument that automaticity of lower order skills is necessary for skilled reading, and metacognition does not act to compensate for lack of automaticity of lower order skills.

In exploring this relationship a clear theoretical framework for task selection must be provided. This framework comes from the literature review presented in the next chapter.

II. LITERATURE REVIEW

A. WORKING MEMORY

Because this study is interested in working memory's relationship to reading in terms of automaticity of lower order skills and metacognition, it is appropriate to look at the research literature under the following headings: working memory, automaticity in lower order reading skills, and metacognition. Pertinent research regarding learning disabilities is presented under these headings.

1. What is Working Memory?

Many theorists have suggested that working memory capacity plays a crucial role in reading ability (Daneman & Carpenter, 1980; Kintsch & van Dijk, 1976). One model of working memory is that of Baddeley's (1979). According to Baddeley (1979, 1986), working memory comprises three components: a central executive which is the control system that selects and operates process; the articulatory loop, which specializes in verbal memory and storage; and the visuo-spatial "scratch pad" which specializes in spatial memory and imagery. According to Baddeley (1986), it is assumed in this model that the articulatory loop, visuo-spatial scratch pad, and the central executive system occupy separate, though interrelated, capacity pools. If the storage demands can be met by the peripheral systems the central executive system uses its capacity for processing activities. When storage demands exceed storage capacity in the peripheral systems some central executive capacity must be devoted to storage, thereby decreasing the central executive's ability to process.

Traditional measures of short term memory such as the digit span and the word span had either not correlated or correlated only weakly with reading (Guthrie, Goldberg, & Finucci 1972; Perfetti & Goldman, 1976). Baddeley's model of working memory offered an explanation for these findings. Short term memory tasks such as the digit span and the word span did not tap a processing component, resulting in insignificant correlations with reading.

A highly significant contribution to working memory research using Baddeley's model was presented by Daneman and Carpenter (1980). In their work, significant correlations between working memory scores and reading were found. In this seminal work regarding working memory, subjects were presented with a series of sentences which they had to process (either by reading or listening), while at the same time trying to retain the last word of each sentence. Working memory performance was measured as the maximum number of sentences processed while correctly recalling the last word. This Sentence Span test is thought to tap both the processing and storage components of the working memory capacity, and correlates well with reading comprehension scores. Daneman and Carpenter also analyzed the types of answers given on standardized reading measures and found that subjects with poorer Sentence Span scores gave qualitatively different, as well as quantitatively different, incorrect answers on the comprehension tests. The authors described the incorrect answers given by subjects with low span scores as more serious errors. For example, when poor readers failed to retrieve a fact or a pronoun referent, their errors frequently reflected a more fundamental misunderstanding of the passage. Their errors might contradict the whole concept of the passage.

Masson and Miller (1983) replicated the findings of Daneman and Carpenter and extended their findings to indicate that the ability to store and process information in working memory is positively related to long-term memory encoding, retrieval of explicitly stated text information in reading, and the integration of text information for the purpose of drawing inferences. It should be noted that both the work of Daneman and Carpenter (1980) and this subsequent work by Masson and Miller (1983) dealt with adults.

As research into working memory's relationship to reading progressed, several lines of questioning occurred. Of note were: (a) does working memory capacity increase in size developmentally, (b) is working memory's relationship to reading task specific, (c) what role does working memory play in the processes of LD children, and (d) what is the relationship of IQ to working memory? These questions will now be discussed.

2. Size of Working Memory

Case, Kurland and Goldberg (1982) showed that working memory capacity did not increase over time as a result of an increased capacity but rather was a result of more efficient use of the existing space. Having demonstrated a linear relationship between increases in word span and increases in speed of word repetition, adults and 6-year-olds were equated on speed of word repetition by manipulating word familiarity. It was shown that adult word spans were no longer different, under these conditions, from the 6-year-olds. Similar findings were then reported for the Counting Span measure by forcing adults to count in an unfamiliar language. It was concluded that developmental increases in memory span do not result from increases in total processing space, but rather that basic operations, with development, become faster and more efficient. Developmental improvement in efficiency will therefore result in improved working memory scores.

Further support for developmental increases in working memory scores comes from Siegel and Ryan (1989). In this study, subjects between the ages of 7 and 13 showed increases in scores on working memory tasks using both Daneman and Carpenter's Sentence Span score and Case's Counting Task.

3. Is Working Memory Task Specific?

Two competing theories have been put forward as to why working memory measures correlate highly with reading scores. In one theory, Daneman and Carpenter (1983) argue that individual differences in working memory performance are linked to the specific processing task of reading. Their work with the Sentence

Span task revealed a strong relationship between span score and standardized reading measures. They argued that this was because this particular working memory task required the subject to use the same reading-specific processes that are contained in the criterion measure. They felt that working memory's relationship to reading was task specific.

Baddeley et al. (1985) posed questions regarding Daneman and Carpenter's theory of task specificity. In their work they used both the Sentence Span measure and Case's Counting Span task. They found higher correlations between the Sentence Span task and reading than the Counting Span and reading. They reasoned that this could be a result of the necessity of a verbal component in the working memory measure or it may be an indication that Case's measure is not a good measure of working memory in that it may not overload the central executive component. The same cautionary note was made regarding Daneman and Tardif's (1987) work. The authors found their Sentence Span task correlated more strongly with reading scores than did their Math Span score, and their Spatial Span scores did not correlate at all.

The second theory, that working memory is task independent, arose out of the work of Turner and Engle (1989) who tried to clarify if working memory was task specific in its relationship to reading. In their experiment they used four complex span measures of working memory (sentence/word, sentence/digit, computation/word, and computation/digit) in order to make inferences regarding the central executive system. They found that the task did not have to be reading-related in order to predict comprehension scores. They also showed that, when the difficulty level of the reading-related or arithmetic-related background task was moderate, the span/comprehension correlation was higher in magnitude than when the background tasks were very simple or very difficult.

Engle et al. (1992) extended their earlier work and tested four hypotheses in regard to differences in working memory and comprehension: a general processing hypothesis, a task specific hypothesis, a general resource capacity hypothesis, and a strategic allocation hypothesis. Using working memory tasks with both arithmetic and language components (based on those of Turner and Engle, 1989), the authors partialled out the processing component and found no differences in the relationships. They argued that this discounted the general processing theory. Next they reasoned that if there was a trade-off between processing and storage (strategic allocation), the increases associated with decreased performance on the processing component of the working memory tasks would disappear when the processing component was partialled out. This was not the case. Engle et al. (1992) argued that these results supported the general resource capacity theory. This theory states that people who are good readers are so because they have larger working memory capacities, independent of the specific task being performed.

The research of Crammond (1992) and Swanson (1992) further supports the task independent theory. In Crammond's work, scores on the Counting Span and the Visual Spatial were not significantly different. Crammond selected subjects who had deficits in arithmetic skill, deficits in reading skill, and deficits in both areas and tested them using the Counting Span and the Visual Spatial measures. The subjects from all three groups were weak in both working memory measures. In Swanson's work, 11 working memory tasks, both visual and verbal were similarly correlated to achievement.

4. Central Processing Difficulties in LD Students

Swanson et al. (1989) studied working memory using Baddeley's model in learning disabled children. In this study the researcher used dual tasks to tap the central processing component of working memory in both verbal and nonverbal conditions, and revealed performance deficits for less skilled readers. It was argued that these results demonstrated a central processing deficiency. In this study subjects were presented with digit strings (sets of three digits and six digits) while sorting blank cards, while sorting cards with pictures of nonverbal shapes, and while sorting cards with pictures of items fitting into categories. The results indicated that the six-digit load condition affected both skilled and less skilled readers' recall, but less skilled readers were more severely affected. Further, the memory load effects were depressed for the verbal and nonverbal sorting conditions when compared with the blank sorting condition for the less skilled readers, while the effects of sorting on recall were minimal for skilled readers. These results suggest that deficiencies in working memory for learning disabled subjects may be pervasive. That is, a central processing deficiency may be involved, since no increased processing efficiency (by employing the peripheral systems) was found for the learning disabled reader.

Central processing deficiencies were also evident in Swanson's work (1989) in which slow learners, learning disabled, average, and gifted children differed in how they shared, discriminated, and selectively allocated resources in central and secondary recall tasks. In this study, learning disabled subjects had verbal IQ abilities above 90; that is, their abilities were in the average range. When asked to recall words in central and secondary task situations, the learning disabled subjects failed to prioritize items and failed to discriminate items in memory (as indicated by their recall of words from the secondary task in the central task situation). The slow learners, on the other hand, compensated for their verbal resource deficiencies by maintaining a constant resource supply between tasks.

5. IQ and Working Memory

Many of the research articles dealing with working memory do not make reference to general intelligence or whether the research concerning working memory is tapping anything other than general ability "g". On the other hand, in the articles that do make reference to IQ ability (Siegel & Ryan, 1989, Swanson, 1989), it would appear that working memory differences occur even with IQ controlled for (using standardized IQ measures).

Further support for the concept that working memory is tapping something other than "g" comes from Globerson (1985) and Porath (1992). Globerson's study tested the theoretical assumption that same-age field-dependent and field-independent children have the same developmental mental capacity. This theoretical assumption was strongly supported. In Globerson's study, children were tested using the WISC-R Block Design as a measure of field dependency; and the Compound Stimulus Visual Information test and the Serial Stimulus Visual Information Test (see Globerson, 1985, for details) as measures of working memory capacity. Children who scored high on the Block Design Test did not score significantly differently on the two capacity tests compared to the children who scored low on the Block Design Test. In addition, Porath's study showed that children who were labelled gifted on several different measures performed in a comparable manner on working memory tasks to average achieving youngsters.

Research concerning working memory should, therefore, examine general intelligence to extend the research findings in this area.

6. Working Memory in the Present Study

In summary, then, tasks which tap both the processing and storage functions of working memory significantly correlate with reading scores. Further, these scores are seen to increase developmentally, not due to increased capacity but rather increased efficiency. Whether the span score is task independent in its correlation with reading has not been clearly demonstrated, although recent articles are indicating that is the case. Further, working memory appears to be tapping something other than "g" in recent research, at least as it is traditionally measured.

When using dual tasks which tap the central processing component of working memory, the research indicates that learning disabled readers suffer from a central processing deficit which is pervasive across verbal and non-verbal conditions.

B. AUTOMATICITY IN LOWER ORDER READING SKILLS

1. Relationship to Skilled Reading

As the research on working memory has indicated, limitations in human performance (i.e. reading) have frequently been explained in terms of limited capacity, which in turn allows differences in performance to be explained in terms of a dichotomy of processes: automatic and controlled. This is because many models of reading indicate that highly automated subprocesses are required for fluent reading, in that highly automated processes utilize less working memory capacity (Gough, 1972, LaBerge & Samuels, 1974; Lesgold & Perfetti, 1981). On the other hand, proficient metacognitive skills are also seen to lessen the burden on working memory (Baker & Brown, 1984). The discussion will now focus on the automaticity of reading subprocesses and then turn to metacognition. However, before dealing with the subprocesses that are automated, it is necessary to clarify what is meant by automaticity in this study.

2. What is Automaticity?

There is some confusion in the literature regarding the nature of automaticity. Automaticity is defined as the activation of a learned sequence of elements in long term memory that is initiated by appropriate input, without stressing the capacity limitation of the system (Schneider & Shiffrin, 1977). Tasks that can be performed quickly, effortlessly, and relatively autonomously are said to be automatic (Logan, 1985; Schneider & Shiffrin, 1977). Word recognition is considered to be automatic when it can take place without attention being directed to it (LaBerge & Samuels, 1974; Perfetti & Lesgold, 1977). According to LaBerge and Samuels (1974), the achievement of rapid automatic word recognition frees cognitive space for higher level comprehension. Research that focuses on the attention-free and obligatory aspects of automaticity have typically measured automaticity employing tasks with the Stroop interference concept (Stroop, 1935) or dual task interference measures. In the Stroop task, subjects name the colour of ink in which a word is printed. The time to name the colour is usually longer when the word is a word that names a conflicting colour than when it is just a string of letters. The longer time suggests that subjects cannot ignore the meaning of the word and hence they must be able to read it without deliberately attending to it (Kahneman & Chajczyk, 1983). Studies using the Stroop task or a picture variant show that highly familiar words begin to interfere with colour and picture naming at the end of the first grade (De Soto & De Soto, 1985; Stanovich, Cunningham, & West, 1981).

Dual-task interference measures indicate that as words become automatic, interference from a secondary source, such as pushing a button when a tone is heard, becomes less intrusive (Horn & Manis, 1987; Schneider & Shiffrin, 1977). A sharp decrease in the amount of interference was noted between first and second grade, and a smaller, but reliable, decrease occurred after third grade (Horn & Manis, 1987).

Measures of automaticity that employ Stroop interference or dual task interference do not deal with the element of speed in automaticity. In fact, Ehri and Wilce (1979, 1983) proposed that word recognition has three stages: (a) an accuracy phase in which children deliberately attend to and process letter and letter-sound relations, (b) an automaticity phase in which they acquire the ability to recognize words automatically, that is, without attention to component letter and letter-sound relations, and (c) a speed phase in which the speed of recognizing words continues to increase slowly. They argue that the attainment of speeded word recognition, more than the ability to recognize words automatically, is crucial to the development of reading comprehension. The increase in interference on Stroop-like measures and the decline in dual task interference after grade three is a result, they argue, of increased speed in word recognition, not in automaticity.

Other research does not draw this distinction between automaticity and speed.

Rather, it views speed as a component of automaticity, that is, speed is a relative measure of automaticity (Bowers, Steffy & Tate, 1988; Jackson & Biemiller, 1985; Logan, 1985; Samuels, 1988; Simpson & Lorsbach, 1987; Spring & Davis, 1988; Wolf, 1986; Wolf, Bally & Morris, 1986). Increases in the speed with which subcomponents of word recognition are carried out (Spring & Davis, 1988; Wolf, 1986; Wolf et al., 1986) and the speed with which word recognition itself is carried out (Jackson & Biemiller, 1985; Simpson & Lorsbach, 1987; Stanovich, 1981) are seen as indications of automaticity and are related to reading ability.

3. Automaticity in the Present Study

While aware of the attentional and obligatory nature of automaticity, for the purposes of this paper, the operational definition of automaticity will be the speed and accuracy with which the operation is carried out, specifically, the speed of lower order reading skills. In this study, the measurement of speed as well as accuracy matches the conceptualization of Ehri and Wilce (1979, 1983) in that the measurement of speed indicates the gradual increase in automaticity of lower order skills over and above accuracy. It will also control for ceiling effects that are often found in simply measuring accuracy of lower order skills. The lower order reading skills that are the focus of this paper are: (a) the speed of word recognition components--namely phonological processing ability, orthographic processing ability, and semantic processing ability and (b) the speed of word recognition itself. These lower order reading skills have been shown to play an important part in reading ability differences as the following research indicates.

4. Word Recognition Components

a.. *Phonological Processing*

Phonological processing refers to awareness and use of the sound structure of a language in processing written and oral information (Wagner, 1988). A meta-analysis of longitudinal correlational studies and training studies regarding the relationship between the development of phonological processing abilities and acquisition of word recognition skills indicates a substantial relationship exists between the two (Wagner, 1988). Median correlations of .38 were found between phonological processing abilities and the subsequent acquisition of reading skills; and a correlation median of .70 was found between phonological processing training programmes and reading acquisition skills. Although there is no agreed-upon taxonomy of phonological processing abilities, Wagner's meta-analysis distinguishes four phonological processing abilities and found that all four contribute separately to the variance found in the acquisition of word recognition skills. The four abilities are: (a) analysis, which refers to segmenting a word into units, and is commonly tested by such tasks as tapping out the syllables of a word or saying a word after deleting one of its phonemes, (b) synthesis, which refers to combining the segments of a word into a whole word, and is tested by sound blending tasks, (c) lexical access, which refers to accessing the referent word in lexicon, and is commonly tested by rapidly naming objects and making the lexical decision of whether a string of letters is a word or a non-word, and (d) coding, which refers to coding information into a sound-based system, and is typically assessed with verbal memory span tasks.

Looking first at analysis, studies show that the ability to segment word parts is an early predictor of later reading ability (Bryant, Bradley, MacLean & Crossland, 1989), as well as a factor in adult reading ability (Pratt & Brady, 1988). Using a phoneme deletion task and a phonological choice task, Cunningham and Stanovich (1990) showed that these two measures, combined with age, accounted for substantial variance in word recognition ability ($R^2 = .36$). Their phoneme deletion task is similar to one used by Pratt and Brady (1988) which accounted for .68 proportion of variance in word recognition ability in adult readers. On the phoneme deletion task, children were instructed to listen carefully to the initial sound of each word the experimenter pronounced. In the first part of the task the subjects listened to ten words and were asked to remove the initial sound of the word and then say the remaining sound segment out loud. For example, to say "park" to the stimulus "spark". For the second set of words, the subject was asked to provide the sound segment that remained when the final phoneme was removed. For example, to say "blas" to the stimulus "blast".

Turning to synthesis tasks, Fox and Routh (1984) showed experimentally that analysis training was not sufficient to improve word recognition skills. Thirty-one kindergarten children were chosen who could not segment words and randomly assigned into one of two groups--one which received segmenting training alone and the other which received both segmenting and blending training. On post-testing both groups showed significant improvement on segmenting and blending, but the group trained in both showed significantly more improvement. Further, on a subsequent reading analog task, involving the paired-associate learning of words, the second group did significantly better than the group who received only segmenting training.

Torgesen et al. (1989) showed that reading disabled children differed significantly from children with normal reading skills on a phonological synthesis task. The authors systematically varied the rate of presentation of phoneme strings in real and pseudowords. Their experiment was based on the model of phonological synthesis developed by Perfetti, Beck, and Hughes (1981) which involved four steps. First, the individually presented phonemes are represented and stored in working memory. Then the phonemes are combined into word-like representations (which involved dropping the irrelevant vowel sound which follows many consonant phonemes--the schwa sound). Next, the lexicon is searched for a real word that matches the phonological string produced. Finally, the word-like representation is compared to the ones found in the lexicon and is either accepted or rejected. Younger children and disabled readers in the study (Torgesen et al., 1989) were significantly less able to perform this task than older and better readers. This work supports the theory that a sound blending task which includes processing steps requiring storage of individual phonemes in working memory will differentiate disabled from non-disabled readers and young readers from older readers. Poorer and younger readers use up more working memory capacity in the process.

These results support the findings of Wagner (1988) that synthesis ability adds separately to variance found in word recognition skills and therefore it is appropriate to use a synthesis task in this study.

Turning to lexical access, as indicated above, lexical access has two components: the speed of retrieval of phonological representation and the ability to match it with a representation in lexicon. The speed of naming studies have shown that continuous, rapid naming of items is correlated to reading ability. Denckla and Rudel (1976a) required subjects to rapidly name pictured objects, colours, letters, and numbers. The dyslexic children were significantly slower than the normal controls. However, Stanovich (1981) used a discrete-trial reaction time methodology to measure the speed with which skilled and less skilled readers (based on global standard reading measures) named colours, pictures, numbers, letters, and words. He found that only words were named more quickly by skilled readers. He argued that this indicated that the naming times for colours, pictures, and numbers, indicating a general name retrieval deficit in dyslexic children, did not appear to be characteristic of less-skilled nondyslexic children. Wolf et al. (1986) argued that these differences in research findings were the result of the different naming and reading measures used. They used four continuous (as opposed to discrete) naming tests based on Denckla and Rudel's (1976a) work. They found that as automaticity in retrieval develops in average readers, the naming-speed/reading relationship moves from a strong, general prediction of reading ability to specific predictions of reading processes. The strongest correlations were between naming speed for graphological stimuli and lower level reading tasks. Wolf et al. (1986) argued that continuous and discrete trial formats should not be compared. Rather, the two formats offer two different sources of information. Reading impaired children do not differ at a basic level of rapid retrieval but differ significantly when the extra cognitive factors that are present in continuous retrieval are added.

Having argued that the inability to perform continuous retrieval differentiated impaired readers, Wolf (1986) looked into continuous retrieval further. She developed two rapid, alternating stimulus naming tests (RAS) according to the rapid automatized naming (RAN) test format of Denckla and Rudel (1976b), and presented them to children in a longitudinal study from kindergarten to grade 2. The two-set task consisted of five letters and five numbers repeated in a fixed A-B-A-B pattern. The three-set RAS task consisted of five letters, five numbers, and five colours repeated in a fixed A-B-C-A-B-C pattern. The RAS measures differentiated average from impaired readers and subtypes of dyslexic children from each other. The children were tested during the last two months of the school year in kindergarten, grade one, and grade two. None of the children who were considered "hard core dyslexics" could complete either RAS test in kindergarten. Further, kindergarten RAS ability was a strong predictor in all children of later reading ability. However, the two-set RAS rate correlated only with lower order reading (single word decoding) rates by grade two. The three-set RAS task continued to correlate with higher order reading skills (comprehension). Error scores did not account for this differentiation. This eliminates visual perception, and symbol identification as possible sources of difficulty.

Spring and Davis (1988) further substantiated that rapid retrieval is related to specific reading skills. They showed that digit naming speed correlated with the reading of irregular words and pronounceable nonsense words. These results were seen as evidence that letter identification automaticity is important to both direct-access and speech-recoding (orthographic and phonological) routes of word recognition. They found that the correlation of digit naming speed with reading comprehension was significantly smaller than its correlation with word recognition. Digit naming speed (but not colour naming speed) is a significant contributor to reading achievement even when verbal IQ is controlled (Bowers et al., 1988).

To summarize, then, research shows that rapid, continuous retrieval of graphological symbols correlates with reading measures, particularly measures of lower level reading skills. With a desire for economy of subjects' time, one rapid continuous retrieval measure was used in this study. The decision to use digit naming speed is based on the reasoning of Spring and Davis (1988). They argued that rapid digit and letter naming correlated strongly with reading ability in the work of Wolf et al. (1986). However, by using the digit naming measure, one can control for letter naming speed being influenced by differing amounts of letter processing experience accrued by good and poor readers (Stanovich, Freeman, & Cunningham, 1983).

The second component of lexical access--matching it to a representation in lexicon--is the phonological processing measure found in Cunningham and Stanovich (1990). In this work, subjects were presented with pairs of pseudowords, for example, "kake-dake", and asked to indicate which pseudoword sounded like a real word when pronounced. The stimulus pairs are both non-words so the only way to respond correctly is to recode the stimuli phonologically. This phonological choice measure combined with the phonemic deletion task discussed earlier and age, accounted for 42% of the variance in word recognition scores, and thus, is appropriate for inclusion in this study.

Turning to the last component of phonological processing--coding--the ability to repeat pseudowords (more than real words) measures the ability to code and differentiates reading ability (Taylor, Lean, & Schwartz, 1989). Taylor et al. (1989) extended the work of Snowling, Goulandris, Bowlby, and Howell (1986), which showed that children with learning disabilities have significantly more difficulty repeating pseudowords than do normal learners. In the studies of Snowling et al., non-word repetition discriminated dyslexic children from non-dyslexic, younger children who were matched to the dyslexics in word recognition skill and IQ. The work of Taylor et al. (1989) confirmed these findings using more difficult words in an effort to control for the ceiling effects of the earlier findings.

b. Orthographic Processing

Although phonological processing deficits are thought to account for the larger share of the variance in word recognition ability, studies show that orthographic processing accounts for some of this variance as well and this ability, in turn, is related to the exposure to print experienced by children (Cunningham & Stanovich, 1990). Using an orthographic choice task and a homophone choice task, these researchers were able to separate orthographic and phonological processing abilities, and to argue that orthographic processing ability contributes uniquely to word recognition ability. The orthographic choice task consisted of words such as "rume-room" which sound alike, and the subjects were asked to indicate which one was a real word. In the homophone choice task, the experimenter asked questions such as "Which is a fruit?" and then presented the subject with a choice "pear/pair". These two measures were used as measures of orthographic processing and accounted for 10% of the variance in word recognition ability. Thus, orthographic processing is linked to word recognition ability, independent of phonological processes, and should be part of this study's structure.

c. Semantic Memory

Semantic memory--the amount of word knowledge available--affects the efficiency with which one reads. For a word to be represented in semantic memory, it should have a category, attributes, and an example (Samuels and Kamil, 1984). As an illustration: a dog is an animal (category); it barks, has four legs, nurses its young, and has non-retractable claws (attributes), and; poodles and collies are dogs (examples).

Various measures have been used to assess a person's semantic memory: sentence verification measures, categorization measures, and vocabulary tests (Samuels et al., 1984). It is semantic categorization and word knowledge (vocabulary) that are of particular interest to this study.

Semantic categorization knowledge has been shown to facilitate the speed with which word meaning is accessed in memory. Proficient word recognition involves the ability to rapidly extract graphemic information and access orthographic, phonemic, and semantic information from individual words (Gibson & Levin, 1975). Although decoding skills have been evaluated in terms of the speed with which subjects can generate a phonological representation (name) of the word (Perfetti & Hogaboam, 1975). Chabot, Petros and McCord (1983) have shown that deficiencies in semantic memory organization, as well as inefficient word recognition skill, can contribute to reading deficiencies. They used a semantic categorization task in which the subject had to indicate, as quickly as possible, whether the words or pictures were from the same category. Although word pairs provided stronger correlations with reading scores, picture categorization correlations with reading were also significant.

In terms of learning disabled readers and semantic memory, Swanson (1986) showed that learning disabled readers are deficient in the amount of word knowledge contained in semantic memory, are deficient in the organization of that information, and are inefficient in activating resources that are present in their semantic memory. A measure of semantic categorization is, therefore, appropriate for this study.

Research has also shown that word knowledge, as assessed through vocabulary tests, is related to reading ability (Eldredge, Quinn, & Butterfield, 1990). However, there is some confusion as to the relationship of word knowledge and working memory. Baddeley, Logie, Nimmo-Smith, and Brereton (1985) found that word knowledge, working memory, and general lexical access were all separately and independently correlated with measures of reading comprehension. On the other hand, Dixon, LeFevre, and Twilley (1988) argued that working memory was related to comprehension because of the relationship of word knowledge to working memory. Using a hypothetical causal model, the authors argued that it was the word knowledge factor embedded in the working memory task which led to the relationship of working memory to comprehension. These findings have important implications in this study. A measure of word knowledge should be included in this study, therefore; not only because it has been shown to be a factor in skilled reading, but also in order to investigate the relationship of word knowledge to working memory further.

5. Word Recognition

According to Gough (1984), word recognition is the foundation of the reading process. He postulates two routes to word recognition--the visual route and the phonological route. In the visual route, the word's physical representation is thought to access directly its meaning in long term memory. On the other hand, the person who uses the phonemic or phonological route first transforms the grapheme representation for the word into a phonological code; that is, they sound the word out using grapheme-phoneme correspondence rules. Support for the visual route comes from the fact that people have the ability to read exception words--that is, words that are not pronounced according to pronunciation rules. Glushko (1979) feels that support for a visual route lies in the fact that there are no consistent spelling-to-sound rules and yet people read. Moreover, people must classify words as exception words before pronunciation. He bases his conclusions on his research that shows pseudowords which closely resemble exception real words take longer to read than pseudowords which are not similar to any exception words. For example, he found that the pseudoword "bint" which resembles the exception word "pint" took longer to read than the pseudoword "bink" which resembles the real word "pink". He concluded that pseudowords are pronounced by comparing their visual appearance with already known words sharing similar graphemic characteristics. The existence of a visual route is also used to explain how the reader can speed read faster than subvocalization would appear to permit (Schwartz, 1984).

On the other hand, the phonemic route helps to explain the ability to read pseudowords. Evidence for the phonological route lies in research in three areas: homophones, regularity, and ambiguity. In regards to the first area--homophones--Rubenstein, Lewis, and Rubenstein (1971) indicated that if the phonological recoding hypothesis is true then a pseudohomophone (a non-word whose pronunciation matches a real word, e.g., "brane") should lead to a lexical entry for that word. Pseudohomophones should be harder to reject than equally pronounceable non-words (e.g., "brone"). The work of Rubenstein et al. supported this concept. Further, spelling errors such as "werk" are harder to detect than those like "wark" (Gough & Cosky, 1977). This does not explain, however, how we recognize that "brane" is a misspelled form of "brain". To solve this dilemma, a spelling check was added to the phonological recoding theory. However, if pseudohomophones are more difficult to read because of phonological recoding it follows that homophones should be easier to read. Research does not provide strong support for this concept of homophone effect (see Gough, 1984, for a review of the literature).

The second area of phonological recoding theory research is regularity. If phonological recoding holds, exception words should take longer to read than non exception words. Research regarding this is mixed. This may be the result of different criteria to choose what constitutes an exception word and may be confounded by the frequency effect on words (Gough, 1984).

The third area of research on phonological recoding is ambiguity of pronunciation. Words such as "steak" where the "ea" sound has many different codes should, by the ambiguity theory, be harder to read than non-ambiguous words. Research does not support this (Gough, 1984).

It would seem, then, that there is support for both a visual and a phonological route. Several researchers have concluded that a dual route exists (Bradshaw, 1975; Meyer, Schvaneveldt, & Ruddy, 1974). Schwartz (1984) concludes after reviewing the literature that the skilled reader decodes words and pseudowords using graphemic and phonological codes but the codes are not necessarily two separate pathways, but can be thought of as types of information stored together in long term memory.

Whether one uses the visual route or phonological route, four factors are thought to affect the speed or automaticity of decoding the word: frequency, regularity, word length, and context. Gough (1984), in reviewing the literature, found that the effects of regularity, word length, and context are more easily detectable in less frequent words, than highly frequent words. Further, he offers a cautionary note regarding frequency. When one is dealing with medium to low frequency words one has difficulty controlling for familiarity. Frequency does not equate with familiarity and this fact should be kept in mind when making word lists for decoding tests.

In summary, then, whether one recognizes a word through a phonological or a graphemic route, the length, frequency, regularity, and context of the word affect the speed with which the reader "recognizes" the word. Spring and Davis (1988) developed two lists of words, one with 40 irregularly spelled words that they argued would be decoded orthographically, and 40 words composed of pronounceable nonsense words which they argued must be decoded phonemically. The words were matched on frequency counts using Kucera and Francis' (1967) norms. Length ranged from three to eight letters. The results of the work of Spring and Davis (1988) supported the hypothesis that two different routes were used in decoding the words. Therefore, their lists are appropriate for inclusion in this study. Context will not be considered, as it does not fit with the word level automaticity concept being looked at in this paper.

C. METACOGNITION

1. What is Metacognition?

Metacognition is the knowledge and control the child has over his or her own thinking and learning activities, including reading. It has received a great deal of emphasis in the last few years (Baker & Brown, 1984; Paris, Cross & Lipson, 1984). Because effective readers have awareness and control of the cognitive activities they engage in as they read, most characterizations of the reading process include the study of skills and activities that involve metacognition (Baker & Brown, 1984). For example, children's reading comprehension can be limited when they do not know about strategies, such as using context to discern new words (Paris & Myers, 1981). Or they may not realize that they should stop periodically to check their own comprehension and take corrective steps when necessary (Garner, 1982; Wagoner, 1983). Even when children know about the existence of strategies, they may not understand their benefits or rules of application clearly (Brown, 1980). These shortcomings can be regarded as metacognitive deficiencies which might be ameliorated with proper instruction (Paris et al., 1984).

In reviewing the literature pertaining to metacognition, Baker and Brown (1984) have stated that metacognitive processes involve three parts: (a) the ability to reflect on one's own cognitive processes, (b) the use of self-regulatory mechanisms by an active learner, and (c) the deployment of compensatory strategies.

a. Reflection on cognitive processes

The ability to reflect on one's own cognitive processes, that is, being aware of one's activities and responsibilities while reading, plays an important role in the child's effectiveness as an active learner. A child must be aware of his or her role as an active participant in reading and of his or her own limitations in relationship to the demands of the reading task, so that he or she can take actions in order to anticipate or recover from problems. Interview investigations have typically been used to discover how children view their role in the reading process. These studies indicate that younger and poorer readers have little awareness that they must make sense of the text (Myers & Paris, 1978; Wagoner, 1983). Work by Cannery and Winograd (1979) indicates that the knowledge that reading is a "meaning getting" activity is age-related. Older children are more likely to try to make sense out of reading material (rather than viewing reading as a decoding exercise) than younger children. Interview methodology, however, has been criticized for its lack of reliability (Baker & Brown, 1984). To gain greater reliability, and yet still access information regarding a child's perspective of his or her role in the reading process, questionnaires with multiple choice responses have been used (Paris et al., 1984) and were employed in this study. However, it must be remembered that knowledge of metacognitive abilities does not ensure that the child actually employs the known strategies during the reading process. Knowledge of the strategies means just that. To discover what the child actually does during reading other measures must be used. Comprehension monitoring--specifically the detection of inconsistencies--has often been used to reveal the reader's actions in the reading process.

b. Comprehension Monitoring

The research on detection of inconsistencies or inadequacies in reading material is based on the premise that readers must be able to realize when they are not comprehending material in order to take compensatory actions. Self-report measures (Olshavsky, 1976-1977), underlining the inconsistencies (Paris & Myers, 1981), monitoring of eye fixations (Grabe, Antes, Thorson, & Kahn, 1987), oral reading miscues (Paris & Myers, 1981), and on-line monitoring (Baker & Anderson, 1982) have all been used to assess whether a subject is able to detect inconsistencies and, therefore, monitor his comprehension.

These studies have made several findings. Firstly, the detection of inconsistencies improves developmentally. Flavell, Speer, Green, and August (1983) had children of kindergarten and second grade listen to taped instructions for constructing block buildings. Some of the instructions had ambiguous statements, unfamiliar words, and insufficient information. Older children were more likely to note the inadequacies than the kindergarten children. Markman (1977) also looked at children's ability to analyze statements given verbally. She had children listen to simple but incomplete instructions on how to play a game. Older children realized more easily that the instructions were incomplete suggesting that older children are engaged in comprehension monitoring activities. In a second study, Markman (1979) gave children in the third, fifth and sixth grades essays to read which had inconsistent information. Children in all grades tested were equally unlikely to report the inconsistencies. Markman investigated whether the lack of detection of inconsistencies was due to poor memory of what had been read or lack of ability to understand what had been read. She concluded that even when the children had probed recall of the information and the logical capacity to draw the inferences regarding the inconsistencies, they failed to do so. However, when the children were warned about the inconsistencies a greater proportion of the older children reported them, indicating that comprehension monitoring is easier for older children if they have an idea of what they are looking for.

Secondly, these studies have shown that detection of inconsistencies differentiates reading ability. Paris and Myers (1981) found that poor readers (assessed on a standard reading measure) were less able to detect nonsense and non-meaningful phrases in reading passages. Their subsequent recall and comprehension of the passage was also lower. Using self-correction while reading, as indication of detection of inconsistencies, Isakson and Miller (1976) and Isakson (1979) found that good readers were able to detect semantic and syntactic anomalies in the sentences better than poor readers. When good readers encountered an anomalous word they tried to fix the resulting comprehension problem by inserting a sensible word. Poor readers simply read the text with the anomalous word. Thus researchers argued that this showed that good readers monitored their ongoing comprehension and took compensatory action.

Thirdly, this research has shown that detection of inconsistencies is better when specific instructions are given to the subjects (Markman, 1979). The fact that subjects make detections when given instructions indicates they have the ability to do so but do not spontaneously employ it. Further support for Markman's conclusion is found in Grabe et al. (1987). In this work, eye fixations (indicative that the reader was aware of inconsistencies) were almost four times as frequent when subjects were given instructions that there were contradictions in the passages, than when no instructions were given.

Fourthly, the research has shown that training in detection of inconsistencies promotes better detection (Paris et al., 1984).

Fifthly, this research has shown that specific types of inconsistencies are more easily detected than others. For example, Baker (1979) found that university students more frequently detected inconsistencies that involved main points than inconsistencies that involved details. Garner and Anderson (1982) investigated whether prior knowledge, recall lapses, or inferential "fix-up" instances were responsible for children's inabilities to detect inconsistencies. Their research concluded that these factors were not responsible for some inconsistencies being detected and not others. Rather, they argued that the material, that is the specific type of inconsistency, was responsible for detection or lack of detection. Zabrucky and Moore (1989) measured children's ability to detect nonsense words (which requires a lexical standard), their ability to detect falsehoods (violations of prior knowledge requiring a standard of external consistency), and their ability to detect inconsistencies (which required a standard of internal consistency) and found that the inadequacies of text were not found equally well. Children used the standards of lexical and external consistency more often than the standard of internal consistency of the text. Developmental patterns were found for all three standards.

In summary, then, the detection of inconsistencies is a well-used means of assessing comprehension monitoring. It shows both developmental and ability differences. It must be kept in mind, however, that the detection of a particular type of inconsistency is not an indication of the ability to detect all types of inconsistencies, nor is it always indicative that the reader can take appropriate compensatory action.

The literature considers several measures to assess the ability to detect inconsistency. These include self-report, oral reading, underlining, interviews, monitoring eye movement, and on-line. When choosing which one to use, several factors come into play. Oral reading is not entirely the same process as silent reading and silent reading is the more common method in regular classrooms. Furthermore, it is possible that increased anxiety in oral reading may affect the scores found. Self report methods suffer from reliability issues (Baker & Brown, 1984). Monitoring of eye movement requires very specialized instrumentation not commonly found in classrooms. Zabrucky and Moore (1989) used combined methods of underlining and controlled interview but found there was little correlation between the two. They recommended that verbal measures should be viewed with caution because of their lack of agreement with performance. Underlining is the means, then, that will be used in this study. The exact nature of the measurement will be described in the methodology section.

c. Employment of Strategies

Turning now to the third part of metacognition, the employment of strategies to either anticipate or compensate for problems encountered, research has shown, as it did in other areas of metacognition, developmental and ability differentiation.

Using the self-report method, Strang and Rogers (1965) found that good readers were able to describe the strategies they used while reading, whereas poor readers appeared to be unaware of their purpose for reading. Smith (1967), using structured interviews, found that better readers adjusted their strategies to accommodate the different purposes of reading. Olshavsky (1976-77), using protocol analysis, found that good readers and poor readers used the same metacognitive strategies in reading but better readers employed the strategies more frequently.

As stated in Chapter I, Perfetti (1985) felt that one of the compensatory strategies that a reader may use is that of schema, i.e., the reader's organized knowledge of the world. Anderson (1984) states that schema affects both the learning and the remembering of information and ideas in the text. Based on previous work (Anderson, 1978, Anderson & Pichert, 1978), Anderson argues that schema facilitates selective allocation of attention, enables inferential elaboration, allows searches of memory, facilitates editing and summarizing, and permits inferential reconstruction. Support for these concepts comes from research that shows that people from differing cultural backgrounds, and therefore having different schemas, give different interpretations to reading material (Steffensen, Joag-Dev, & Anderson, 1979). Comprehension of the material and recall is affected by the schema that the reader places the story in, their schema in turn is affected by their background. One of the examples in this research is a story regarding a wedding party involving the traditional "something borrowed, something blue" theme. A person of East Indian background sees the bride as being very poor, having to borrow a dress, whereas a person of North American background, sees the story as one concerning a time-honoured tradition.

Research that manipulates the background knowledge of the subjects (Anderson, Spiro, & Anderson, 1978) or manipulates the perspective of the reader (Pichert & Anderson, 1977) also supports Anderson's summary of schema's role. Ohlhausen and Roller (1988) researched the metacognitive strategy of using text and content schema in reading. Using three texts--a content schemata text, a structure schemata text and text containing both--they required subjects from fifth, seventh, and ninth grades to underline the seven most important sentences in the passage. They argued, based on Anderson (1984), that the selection of important information is one major function of schema and, thus, a score on this task would provide evidence of the use schema. They also scored subjects on their verbal reports of strategies used in the underlining task. Results were consistent with the hypothesis that content and structure schema influence the processing of text. They found developmental differences and increased scores when both schemas were used. Measurement of schema use, therefore, is appropriate as one means of discovering what compensatory strategies are used by the reader.

Although Ohlhausen and Roller (1988) used underlining of the important elements of the story, this process may disadvantage younger children since it is a task not often done in the early grades at school (although underlining of mistakes is). Inferential questioning, which Anderson (1984) also argues is a means of assessing schema use, is more common. The use of inferential questions to ascertain the reader's understanding of the text, however, is complex. For example, research has shown that the use of clauses such as "because" influence the reader's ability to make inferences (Nicholson & Imlach, 1981); variations occur in inferencing ability because of differences in prior knowledge (Pearson, Hansen, & Gordon, 1979); the more important the information is for comprehension, the more likely the reader is to make the inference (Singer, 1980); and the child's background knowledge competes with the text data for priority in question-answering (Nicholson and Imlach, 1981).

Although some inferences are easier to make than others, the ability to make inferences remains a recognized means of assessing the employment of schema by the reader (Anderson, 1984), and, therefore, a passage with inferential questions will be used in this study.

A second method of evaluating the use of compensatory strategies is the cloze technique (Di Vesta, Hayward, & Orlando (1979). In this method the reader is presented with reading material in which words have been deleted and they are simply asked to supply the missing words. Good readers made better use of contextual information and redundancy, and complete the texts more easily than poor readers. Therefore, a second measure of compensatory strategy use, in this study, will be a cloze task.

In summary, then, metacognition plays an important role in reading comprehension. It involves being aware of one's role in the process of reading, the on-going monitoring of reading, and then the deployment of compensatory strategies when difficulties are encountered. The research shows that metacognitive comprehension increases with age and ability.

D. RESTATEMENT OF THE PURPOSE OF THE STUDY

In summary, the literature has indicated that automaticity of lower order skills, metacognition, and working memory play a major role in skilled reading. The present study examines the relationship between lower order processing skills, metacognition, and working memory within a non-disabled and LD sample. The relationship among these three processes is considered in light of two theories: modularity and general resource capacity. Proponents of the modularity theory argue that automaticity of lower order skills are encapsulated processes that operate independent of a general resource system (i.e., working memory) and high order processing (e.g., metacognition). The resource capacity model suggests that a general working memory system is related to lower order processing, as well as higher order skills such as metacognition. Implicit in this model is the concept of a central executive responsible for the control and organizing of process. It is the purpose of this study to investigate the relationship between automaticity, working memory, and metacognition as a function of ability groups. Since research indicates that performance on individual tasks within the constructs changes developmentally, the relationship of the three may also change. Therefore, this relationship is looked at from a developmental perspective.

E. HYPOTHESES

The literature has indicated that LD readers have less skill in areas of automaticity of lower order reading skills, metacognition, and working memory. It would be expected, but should be tested to confirm, that the LD readers score lower on the tasks of automaticity, metacognition, and working memory chosen in this study. Further, performance differences on these three processes would be expected to be better in older than younger subjects for both ability groups. Therefore, the following hypotheses are formulated:

1. LD readers will score significantly lower on working memory measures than non-disabled readers.
2. LD readers will score significantly lower on measures of automaticity than non-disabled readers.
3. LD readers will score significantly lower on measures of metacognition than non-disabled readers.
4. Scores on working memory measures will increase developmentally.
5. Scores on automaticity measures will increase developmentally.
6. Scores on metacognition measures will increase developmentally.

Because it is the purpose of this study to look at the intercorrelations among automaticity of lower order skills, metacognition, and working memory processes in light of two competing frameworks (resource capacity model and modularity model) the following hypotheses for correlational patterns are formulated:

7. i) Significant intercorrelations among working memory, automaticity of lower order skills, and metacognition would lend support to the resource capacity model. Non-significant correlations among working memory, automaticity of lower order skills, and metacognition would support the modularity theory.

   ii) Since the individual tasks within the constructs change developmentally, the overall correlational pattern may change developmentally. The correlational patterns will be looked at in grade three and grade six groups.

   iii) Because it could be argued that LD readers are deficient in all three major processes, the intercorrelation among these processes may be different from their average reading counterparts. The intercorrelations will be compared in the LD and non-disabled groups.

The literature review has provided the theoretical framework for choosing particular types of tasks to measure the constructs of working memory, automaticity, and metacognition. The next chapter will describe the instruments used, in detail, as well as subject selection and data collection.

III. METHODOLOGY

This chapter describes procedures for collecting and analyzing the data. This description is divided into three major sections: (a) design, (b) instrumentation, and (c) task administration.

A. DESIGN

It is clear that reading is a complex task which is unlikely to be studied adequately using any single method or approach. Engle et al. (1992) have argued that there are two methods used to study individual differences. One approach is the use of ANOVA. By this method subjects with high and low scores on a measure are treated as two independent and homogeneous groups and tested as to how they compare on other manipulated variables. Engle et al. argue that while this method lends itself to studying the effects of different independent variables it has deficits. Grouping subjects does not allow useful information about the variability of subjects within each group. "Further it is more difficult with this approach to study the contribution of the variables' common and unique variance" (p. 977). The other approach they recommend is the correlation-oriented one, whereby subjects over the entire range are studied. The relationships among variables of interest are studied to find unique and common variance. They conclude that the ANOVA and correlational approaches are best when used together and consequently they are both used in this study.

1. Subjects

Eighty children enrolled in two urban school districts were selected for this study. Forty children were learning disabled and 40 children were average achievers. The sample included 40 children each from grade three and grade six, selected randomly from 21 schools. Table 1 provides psychometric, gender, and ethnic information.

As shown in Table 1, standard scores for the learning disabled subjects were in the average range on the Coloured Progressive Matrices (1976) and on the WISC-R, while their scores in reading achievement on the Kaufman Test of Educational Achievement-Short Form were below 90. Diagnosis of children with learning disabilities had been made by the school-based, multidisciplinary assessment team (which includes a certified school psychologist) based on discrepancy scores. All but three of the children in the learning disabled group had mathematics scores between the 25-50%ile based on standard measures (KTEA, WRAT, or Woodcock Johnson). Children in this sample match Rourke (1985), Siegel and Linder (1984), and Fletcher's (1985) low reading subtype of learning disabilities rather than the "poor readers of the garden variety" type who are low in most academic areas. Mathematics and WISC-R scores were not available for the non-disabled students.

An attempt was made to have the control group chosen from the same schools as the learning disabled group. This was not, however, always possible. All but two

Table 1
Descriptive Statistics of Sample Population

	Control	LD
IQ (Raw) Coloured Matrices	30.75 (SD 11.04)	26.97 (SD 4.98)
IQ (%ile) Coloured Matrices	61.45 (SD 22.92)	46.35 (SD 21.07)
WISC-R		95.85 (SD 5.96)
Age (months)	117.95 (SD 18.43)	121.75 (SD 16.94)
Male	24	32
Female	16	8
Caucasian	37	37
Chinese	3	2
First Nation	0	1
KTEA Score (raw)	34.65 (SD 8.21)	19.42 (SD 9.85)
KTEAS Score (standard)	111.60 (SD 19.07)	79.72 (SD 7.11)
Mathematics	-	92.92 (SD 5.56)

children attended middle-class schools. The two exceptions attended inner-city schools. All children completed the tasks, but because of audio recording errors some tasks were not scoreable for six children. All tasks were scoreable from 72 students; 17 grade 3 control, 17 grade 6 control, 18 grade 3 LD, and 20 grade 6 LD.

2. Selection of Subjects

After obtaining appropriate permission from the University of British Columbia, appropriate permission was obtained from the Director of Instruction, Curriculum and Assessment and the Director of Student Services from the suburban school districts chosen. Then subject selection procedures were undertaken.

School district screening committee review forms were obtained in order to select 40 learning disabled subjects. Each learning disabled subject in the study was registered in grade three or grade six and had an average or higher score on the Wechsler Intelligence Scale for Children-Revised (WISC-R) and a significant lag in reading achievement as measured by the Woodcock-Johnson Psychoeducational Battery Reading Achievement score or other standard reading measure used in the school district. Further to this, each learning disabled subject had been referred by his or her teacher and area counsellor to the screening committee, which included a certified school psychologist, for placement in a program for learning disabled students and was being presently served within a learning disability special education program. No evidence or history of neurological abnormality, emotional disturbance, or cultural deprivation was apparent.

Principals of those schools where the learning disabled subjects attended were asked to participate in the study. Upon receipt of principal approval, a random sample of grade three and grade six subjects was also chosen from the non-disabled students. Letters were sent to the parents or guardians of each subject. Letters contained a description of the study and sought permission from the parents for inclusion of their child in the study. Children from the regular program were not receiving any remedial help and were not classed as ESL. Copies of the letter and the consent form appear in Appendix A.

B. INSTRUMENTATION

1. Lower Order Reading Measures

The lower order reading tasks that were used in the study are outlined below. For each lower order task, scores were obtained for accuracy as well as time. To obtain a time score the task presentation was tape recorded and times were taken to the nearest second. A rate score was then obtained by dividing the number correct by the time taken to do the task. It is this rate score that was used in subsequent analysis. It should be noted that the rate score is an indication of the amount of processing that occurs in a given time, not the average time it took to do the task. In subsequent analysis the correlations are therefore positive for more skilled readers.

Most research dealing with latency variables uses the time it takes to do the task and therefore negative correlations appear between latency and achievement Each rate score used in the study was verified a second time by a "blind" repetition of scoring. Appendix B contains the complete set of instructions and test items for each of the 22 tasks. The following is an outline of the tasks' salient points.

a. Phonological Processing Measures

Based on Wagner's work (1988), the phonological processing measures incorporated in this study included an analysis component, a synthesis component, a lexical component, and a coding component.

To assess the analysis component of phonological processing, the phonemic deletion task of Cunningham and Stanovich (1990) was used. Children were instructed to listen carefully to a group of words. In the first part of the task, the subjects were asked to listen to each of ten words (smart, globe, spark, crib, strip, spot, trick, snipe, smack, and stop) and then asked to remove the initial sound of the word and say the remaining sound segment out loud. For example, the subject was to say "park" to the stimulus "spark". Subjects were given three practice words: block, grab, and crown. The second part of Cunningham and Stanovich's task was not administered. The maximum accuracy score was 10 and the minimum score was 0. Cunningham and Stanovich (1990) report split-half reliability of .82 for this measure.

To assess the synthesis process in phonological processing, the Roswell-Chall Sound Blending task (1959) was used. The subject was presented with phonemes to blend together into a word. The maximum accuracy score was 30 and the minimum score was 0. Yopp (1988) reported reliability of .90, using Cronbach alpha, for this measure.

To assess the two components of lexical access--speed of retrieval of phonological representation and matching it with a representation in lexicon--two measures were used. To assess speed of retrieval, digit naming speed was measured with a continuous list procedure developed by Spring and Capps (1974). Subjects were required to say the names of 100 randomly ordered digits as rapidly and accurately as possible. The digits, excluding the two syllable digits 7 and 0, were typewritten on a card in a single row using 12 Courier type. The digits were typed in 10 groups, with 5 digits in a group. There were no spaces within groups, but consecutive groups were separated by a single space. The card was placed in front of the subjects and they were asked to read the digits from left to right as quickly as they could. Two trials were given, separated by a 1 minute rest. Maximum accuracy score was 100, the minimum score was 0.

To assess matching the word with a representation in lexicon the phonological choice measure used by Cunningham and Stanovich (1990) was used. This measure was adapted from work done by Olson, Kliegl, Davidson, and Foltz (1984). The subjects viewed pairs of pseudowords (eg. kake-dake, filst-ferst, bote-boaf, dorty-derty) and indicated which pseudoword sounded like a real word when pronounced. Maximum accuracy score was 25 and the minimum score was 0.

To assess phonological coding, pseudoword repetition was used based on the work of Taylor et al. (1989). The test consisted of 30 nonsense words, each of which was derived from a polysyllable word. The real words were transformed into pseudowords by means of phoneme substitutions. Children were told that the examiner would say a series of nonsense words and that each word should be repeated immediately after they heard it. Two practice words were given. Children were allowed to self correct but each pseudoword was presented only once. A word was considered accurate if all major phonetic components could be discerned in the correct sequence. Maximum accuracy score was 30, the minimum score was 0.

b. Orthographic Processing Measures

To assess orthographic processing, the orthographic choice task of Cunningham and Stanovich (1990) was used. The subjects viewed pairs of letter strings that sound alike (e.g. rume-room) and indicated which one was spelled correctly by saying "A" or "B". Five practice trials were given. The pairs involved were: room-rume, young-yung, turtle-tertle, snow-snoe, taik-take, goat-gote, please-pleese, sleap-sleep, streat-street, between-betwean, deep-deap, eazy-easy, face-fase, heavy-hevvy, hert-hurt, laik-lake, nead-need, roar-rore, sheep-sheap, smoak-smoke, tape-taip, toward-toard, wait-wate, clown-cloun, circus-sircus, wroat-wrote, wurd-word, cote-coat, few-fue, and keep-keap. Maximum score was 25, the minimum score was 0.

The homophone choice task of Cunningham and Stanovich (1990) was also used. The experimenter read a question orally to the subject e.g. "Which is a fruit?"). Then the subjects were presented with two homophones (eg. pair, pear) and asked to respond. Scores for speed and accuracy were taken. Five trials preceded the experiment. The pairs involved were: rose-rows, tail-tale, ate-eight, cents-sense, flew-flu, none-nun, right-write, groan-grown, bare-bear, ant-aunt, flour-flower, one-won, plain-plane, sail-sale, pain-pane, hair-hare, poor-pour, blew-blue, deer-dear, hall-haul, pair-pear, stake-steak, week-weak, brake-break, and pray-prey. Maximum score was 25, the minimum score was 0.

c. Semantic Processing Measures

Knowledge of semantic category organization has been shown to facilitate the speed with which word meaning is accessed in memory (Chabot et al., 1983). A categorical decision task (developed by Chabot, Miller, & Juola, 1976) was used to measure semantic memory access. Ten exemplars from 10 different categories, using Battig and Montague norms (1969), were chosen as stimulus material. The categories were: units of time, metals, four-footed animals, furniture, human body parts, relatives, fruits, sports, colours, and kitchen utensils. For the present study, only highly typical items from each category were chosen. The subjects responded "yes" or "no" when the card with the two words written on it was presented. Maximum accuracy score was 35, the minimum score was 0.

A word knowledge score was obtained by administering the odd numbered words on the vocabulary subtest of the Gates-MacGinitie Test (Gates & MacGinitie, 1965). This test consisted of the presentation of single words followed by response options. Subjects were directed to indicate the response which meant the same as the target word. Maximum accuracy score was 23, the minimum score was 0.

d. Word Recognition Measure

The word recognition task of Spring and Davis (1988) was used. Two lists of words were presented to the subject for decoding. One list of words is real words and therefore thought to tap the orthographic route to decoding and the other list is comprised of words that are not real but can be sounded out. This second list is thought to tap the phonological route to decoding. The words were typed in Courier 12 type on an 8 x 11 paper. The subjects were asked to try to say the word even if they were not sure. Maximum accuracy score was 40 for each list, the minimum score was 0.

2. Working Memory Measures

Salthouse and Babcock (1991) indicate that although individual working memory tasks such as the Counting Span used by Case et al., (1982), the listening

(1982), the listening and reading span used by Daneman and Carpenter (1980), and the various tasks used by Turner and Engle (1989) appear to satisfy the theoretical criteria for the assessment of working memory, no single one of them is likely to provide a pure or completely accurate estimate of the working memory construct because of the influence of task-specific factors.

That is, the variance on any given measure can be postulated to involve variance associated with the theoretical construct, variance associated with the specific manner (e.g., procedures, stimulus materials, etc.) in which the construct is assessed, and unsystematic or error variance. Therefore, to emphasize the variance associated with the working memory construct and to minimize variance specific to the particular procedures used to assess working memory, it is desirable to obtain multiple measures of the construct (p.265).

Given this rationale, the present study employed multiple measures of working memory to provide more reliable and generalizable indicators of individual differences in working memory.

a. Verbal measures

Two verbal working measures were used, the Sentence Span and the Counting Span. Following Daneman and Carpenter's work, 20 unrelated declarative sentences of 7 to 10 words in length were used for the Sentence Span task. Sentences were randomly ordered in groups of 3, 4, 5, or 6, with two sets at each level. In order to ensure that the children comprehended the sentences and did not merely treat the task as one of short term memory for target words, subjects were required to answer a question at the end of each presentation. Questions were related to a randomly selected sentence in the set (except the last one). The sentences had been written for and used with children in work by Swanson et al. (1989) as the original Daneman and Carpenter measure was used with adults. A basal-ceiling method of administration was used, with testing ending when a subject missed all sets at one level. Maximum score possible is 8, the minimum score was 0.

The Counting Span task used was designed by Case et al. (1982). It requires the subject to count a set of objects and to recall the number counted after the set is removed. The number of sets to be counted is increased up to the point where the subject can no longer recall all the totals. There are five levels of items, with three items per level. The first level requires that only one total be recalled, with successive increments of one up to the fifth level. The test used a set of 8.5 by 11 inch white cards with green counting dots affixed in random patterns. Scattered among the green dots were yellow distractor dots.

Subjects were first presented with a practice card and told that once it was turned over, they were to count the green dots out loud and point to each one. Counting could be done at whatever speed was most comfortable. After the card was counted, a graph card was placed over it and the subject was asked, "How many dots were there?" If the child answered correctly and indicated that the procedure was understood, the test was begun. If not, more practice was given. Sets were presented one card at a time. Subjects were instructed to begin counting each new card as soon as it was presented. When a subject finished counting the last card in a set a graph card was presented as a signal to recall totals. Subjects were instructed to attempt ordered recall. A basal-ceiling method of administration was used, with testing ending when a subject missed all three sets at one level. In the original scoring procedure a set was scored as correct as long as the last card total was not mentioned first. Each correct score was given 1/3 of a point for a possible total of 5. In the present study, to avoid fractions, each correct answer was given 1 point and to maintain consistency with other working memory tasks only totals recalled in the correct order were considered correct. Maximum score was 15 and the minimum score was 0.

b. Visual-spatial measures.

Two non-verbal measures were used, a Visual-spatial Span task using shading (based on the measure developed and used by Crammond, 1992, and used by Porath, 1992) and a second called "Mr. Cucumber" (similar to that found in Case & Kurland, 1978). The purpose of the visual matrix is to assess the subject's ability to remember visual sequences within a matrix. The subject was first shown a card depicting a matrix with one or more shaded squares for 3 seconds. To minimize the possibility of performance enhancement due to iconic storage, a blank black card was then presented for 3 seconds followed by an empty matrix. A processing question was then asked, "Is there a shaded square in the last column?" To ensure that the subject understood the word column, the examiner pointed to the last column on the blank matrix. After answering the processing question, the subject was asked to put an X on the squares that were shaded. To control the use of mnemonic strategies, matrices having some sort of symmetry or familiar pattern were eliminated from the set of potential test items. The matrices range in difficulty from 1 shaded square within a 4 x 4 matrix to 5 shaded squares. A basal-ceiling method of administration was used, with testing ending when a subject missed all four sets at one level. In the task presentation of Crammond (1992) and Porath (1992) the processing question was not included. The adaptation, in the present study, is similar to that done by Swanson (1992) and was done to keep the working memory tasks as parallel as possible to the Sentence Span of Daneman and Carpenter. In the scoring used by Crammond (1992) and Porath (1992) one point was given if the subject answered two of the three parts at any one level correctly. An additional 1/3 of a point was given if the subject answered 1 part of the next level correctly. In the present study, in order to avoid fractions, 1 point was given for each of the four parts at each level answered correctly, for a maximum score of 20 and a minimum score of 0.

In the second Visual-Spatial task, Mr. Cucumber, a clown figure, containing one or more coloured spots on different body parts, was presented to the subject for 5 seconds. To prevent iconic storage, a sheet of graph paper was then presented for 3 seconds and followed by a blank clown figure. A processing question was then asked, "Is there a dot on the right arm?" Again, this processing question was included to keep the tasks as parallel as possible. After answering the question the subject was asked to draw a circle on the blank clown figure to indicate where the coloured circles had been. The number of spots varies from 1 to 6. A basal-ceiling method of administration was used, with testing ending when a subject missed all three sets at one level. In the original scoring 1/3 of a point was given for each step correctly answered. In this study each level was given 1 point for each step correctly answered for a total possible of 18 and a minimum of 0.

c. *Dual task measures*

Two concurrent memory tasks were used. The literature indicates that deficiencies in the memory of the learning disabled are a result of central processing deficiencies. If this is so, a concurrent memory task is necessary to isolate the central processing component in working memory. One concurrent task that was used is that which is found in work by Swanson et al. (1990) and which was adapted from work of Baddeley and Hitch (1974). Digit strings were verbally presented while the subject attempted to sort cards into categories. Baddeley and Hitch (1974) found that, in such activities, the main task difficulty (sorting) interacts with concurrent memory load of six (but not three) digits suggesting that demands are being made on the central executive. The digits were presented at a rate of one every 2 seconds while the subjects sorted cards into four piles. The subjects were instructed to sort one card between each digit presentation. After the digit sequence was completed the subjects were asked to recall the digit sequences. The subjects were given three practice trials and then participated in three sorting conditions: blank sort, semantic sort, and the nonverbal shape sorting. Dependent measures were digits with order. Maximum score was 4, the minimum score was 0.

A second concurrent task was used identical in nature to the above except that coloured squares were presented rather than verbal digits. The subjects were asked to recall the colours presented by pointing to a grid with coloured squares.

3. Metacognitive Measures

a. Questionnaire measure

A metacognitive questionnaire was used. According to Baker and Brown (1984) a person must be aware of his or her role in reading comprehension, that is, he or she must feel a sense of control and be aware of his or her strategic processes in the reading process, in order to use metacognitive skills. It is, therefore, relevant to assess how the subjects view themselves in relation to the reading process. A metacognitive questionnaire, adapted from Paris et al., and used in research by Swanson and Trahan (1992) was used. It has a multiple choice format which allows for easier analysis of responses than an interview format. The latter has been criticized in Baker & Brown (1984). The twenty questions in the questionnaire cover fundamental comprehension activities such as understanding the purposes of reading. The complete questionnaire is in Appendix B. Maximum score for the questionnaire was 80 and the minimum was 20.

b. Inconsistencies task

A detection of inconsistencies task was used. According to Baker and Brown (1984), a child must be aware of inadequacies in their comprehension of a passage in order to implement compensatory strategies. One method that has been used to assess knowledge of comprehension inadequacy has been detection of inconsistencies in reading passages. Because error detection depends on strategic text processing, it is a good index of evaluation, planning and regulation. Based on Zabrucky et al. (1989), subjects were presented with six expository passages of six sentences at grade level. Two of the passages contained violations of internal consistency, two contained violations of external consistency, and two contained violations of lexical standard. Since previous research has indicated that children have a better opportunity of detecting inconsistencies if they are told the passages have problems, specific instructions were given in this study. The subjects were told that the paragraphs had problems in them. Examples were also given. Subjects were told to underline anything in the paragraphs that they thought was problematic. To receive credit (1 point) for a correct response, a subject had to underline the problematic information (but not any other information). The subjects were asked to follow along the passage as it was read to them. Maximum score was 6, minimum score was 0.

c. Strategic compensatory tasks

A cloze test was used. According to Baker and Brown (1984), one of the compensatory strategies used in metacognition is use of context. The cloze method of testing allows one to measure the use and accuracy of this compensatory strategy. A cloze test was constructed similar to that done by Paris et al. (1984). The passage used was taken from the Classroom Reading Inventory (Silvaroli, 1976) at grade three and grade six levels. With the exception of the first and last sentences of the passage, every fifth word was deleted from the text. Subjects' cloze responses were scored according to the following procedure: (a) responses that were both semantically and syntactically appropriate to the missing word were awarded 2 points, (b) responses that were either semantically or syntactically appropriate but not both were awarded 1 point, and (c) answers or responses that were neither semantically nor syntactically appropriate were awarded 0 points. Semantic appropriateness was judged in relation to the text meaning and syntactic appropriateness was judged in relation to the sentence construction. Subjects' total scores thus ranged between 0 and 14. The subjects were asked to follow along as the passage was read to them. So that the results were not confounded, the subjects gave their responses orally rather than in written form.

d. Use of schema

Based on Anderson (1984) the use of schema was measured by the ability to draw inferences in an inferencing task. Three passages (at grade level and using vocabulary common to the grade) were given to the subjects. Each subject was asked three inferential questions regarding the passage. Passages were of moderate length (150-220 words). The subjects were asked to follow along as the passage was read to them and answer inferential questions regarding the passage, while the passage was still before them. They responded orally. This allowed them no chance at guessing (which is inherent in a multiple choice format), did not bring in a secondary factor of writing their answers, and yet allowed for the subjects to justify their responses, as recommended by Rupley and Blair (1988). Answers were recorded for scoring. Narratives (both the grade three and the grade six levels), as well as the questions, are at the end of the chapter. A score of 2 was given for a complete correct answer and a score of 1 was given when it was perceived that the subject had the general idea but was unable to give a complete answer. Scoring was checked by a second examiner with results in total agreement . Maximum score was 18, minimum score was 0.

4. Standard Testing Measures

a. Reading Measure

The Kaufman Test of Educational Achievement-Reading Test-Short form was administered. The KTEA-short form has excellent psychometric properties. Mean split half reliability coefficients for the reading decoding, reading comprehension, and reading composite scores are .95, .92, and .96 respectively, by grade, in the standardization sample and .95, .93. 97 respectively, by age. Test-retest reliability coefficients for grades one to six are .95, .92 and .96. Standard error of measurements are small. Good evidence for content, construct, and concurrent validity are shown in the manual. An example of concurrent validity evidence presented is that KTEA Reading Decoding correlated .84 with the Peabody Individual Achievement Test Reading Recognition and KTEA Reading Comprehension correlated .74 with PIAT Reading Comprehension. Good evidence for the technical adequacy of the KTEA can be found in Sattler (1988). Scores were reported in raw as well as standard scores based on age norms. Maximum raw score is 52 and minimum is 0.

b. Cognitive Measure

In order to discover if working memory taps a skill in reading other than general intelligence, a cognitive measure was used to act as a covariate in the analysis. The Coloured Progressive Matrices (Raven, 1976) was administered. Maximum raw score is 36 and minimum is 0.

C. TEST ADMINISTRATION

Testing of the 80 students was done over two, 1 1/2 hour time periods. Four sets of test order were constructed using random numbers and then randomly assigned for use with subjects. The only stipulation to the random ordering was that the four tests (KTEA, inferencing task, cloze task, and detection of inconsistencies) which required the greatest amount of administration time were divided evenly between the two sessions, that is, two of the tasks were in the first half and two of the tasks were in the second half. Data was collected by one examiner having level "C" training (Cronbach, 1970).

1. Data Entry

A summary information sheet containing all test results was maintained for each subject. This sheet was coded to protect confidentiality.

2. Data Analysis

The data analysis was completed in the following stages:

1. Preliminary analysis including means and standard deviations was computed.
2. A stepwise discriminant analysis was computed to determine best predictor variable of ability group at the task level.

3. A 2 (ability group) x 2 (age/grade) MANCOVA across tasks was completed to determine if there were significant differences between groups on the three constructs
4. When significant MANCOVAs were found, follow-up ANCOVAs were computed to determine ability and age differences.
5. Correlational analysis was done at the construct level to test the resource capacity or modularity model as a function of ability group and age-level.

All analyses were performed using SAS.

IV. RESULTS

A. PRELIMINARY ANALYSIS

1. Subjects

Table 2 presents the means and standard deviations for all experimental variables for the total sample. Table 3 presents the means and standard deviations for all experimental variables used in the subsequent analysis as a function of ability group. Table 4 presents the means and standard deviations for all experimental variables as a function of age and ability. In terms of age and psychometric scores, grade 3 non-disabled subjects had an age mean of 100.05 (*SD* 3.57) months, a mean Raw IQ of 30.15 (*SD* 1.55), and a mean KTEA Raw score of 28.40 *(SD* 6.58). Grade 3 learning disabled subjects had an age mean of 105.30 (*SD* 3.29) months, a mean Raw IQ of 23.50 (*SD* 3.81), and a mean KTEA Raw score of 11.10 (*SD* 5.21). Grade 6 non-disabled subjects had an age mean of 135.85 (*SD* 3.23) months, a mean Raw IQ of 31.33 (*SD* 2.88), and a mean KTEA Raw score of 40.90 (*SD* 3.56). Grade 6 learning disabled subjects had an age mean of 138.20 (*SD* 3.01) months, a mean Raw IQ score of 30.45 (*SD* 3.31), and a mean KTEA Raw score of 27.75 (SD 5.02)

2. Factor analysis

Because a large number of dependent measures were used to assess reading performance, it was necessary to determine if there was some independence in the tasks. Thus, a principal components analysis with a varimax rotation to orthogonal solution was performed on all standard scores. The criteria for retaining factors was a minimum eigenvalue of 1.0 (Kaiser's criterion) and an item load of .35. This latter criterion was based on the interpretability of items within the factor solution, as well as the fact that minimum loadings between .35 and .50 are commonly used in the literature. On the occasions when a variable loaded .35 or above on two factors, it was placed in the factor that provided the best conceptual match. The five factors that emerged are shown in Table 3. As can be seen from the table, the lower order skills loaded on Factor 1 and Factor 4. The working memory measures with the exception of Visual Spatial (shading) loaded on Factor 2. All the metacognitive variables with the exception of the metacognitive questionnaire loaded on Factor 3. The metacognitive questionnaire loaded on Factor 5. From the five factors found there is evidence that tasks load on difference constructs. Because of sample size, however, it was decided to put the tasks into composite scores developed *a priori* from the literature.

3. Individual tasks

A large number of processing tasks were included in this study because they tap processes thought to be important in skilled reading. These processes are not independent, since they share some task characteristics with other measures. Establishing the interdependency of these measures is difficult since reading involves a hierarchical arrangement of subcomponent processes. Notwithstanding this, each task was chosen because its most salient component is thought to tap a process that is important in reading. It was one purpose of this study to determine which of these tasks best determined ability group membership. Therefore, a stepwise discriminant analysis was performed to determine which of the experimental tasks, based on squared partial correlations, best discriminated between ability groups.. The measures reported in Table 3, as well as age and Raw IQ, scores served as predictor variables. The criterion measure was ability-group based on the school classification (i.e., IQ and achievement test scores). Prior to the analysis all scores were transformed to Z scores based on the total sample because of the possible inequality of units that may be reflected in the tasks.

The single best predictor of ability was Vocabulary Rate, producing a partial R^2 = .42, $F(1, 70) = 51.91$, $p < .0001$. Other significant predictors were Phonemic Deletion [Partial R^2 = .26, $F(1, 69) = 23.79$, $p < .0001$], Age [Partial R^2 = .18, F (1,68) = 14.99, $p < .001$], Inconsistencies [Partial R^2 = .17, $F(1,67) = 14.69$, $p < .001$], Concurrent Memory (Colour Blank) [Partial R^2 = .10, F (1,66) = 8.02, $p < .01$], Sentence Span [Partial R^2 = .06, F (1,65) = 4.18, $p < .05$], and Real Word Recognition Rate [Partial R^2 .05, F (1, 64) = 3.97, $p < .05$]. No other variables significantly predicted ability group classification ($p < .05$). In sum, this analysis suggests that lower order processes best predict ability group classification. However, processes related to working memory and metacognition all yield significant variance in ability group classification. Interestingly, IQ did not contribute significant variance, a finding consistent with Siegel (1989b).

B. CATEGORIES OF PROCESSING

As outlined in Chapter II, 26 experimental variables were chosen from previous research on reading skill differences in processing: in areas of automaticity, metacognition, and working memory. Tasks reflective of each processing area are shown in Table 2. These categorizations were done *a priori,* based on the existing literature. One reason for giving multiple tasks for each construct was to be able to assess relationships at the construct level rather than at the task level because of the isolated variance that is possible at the task level (see Salthouse & Babcock, 1991, for discussion). Further, using multiple measures of a hypothetical construct enhances the reliability and validity of the findings. Composite scores, reflective of the three categorizations of processes shown in Table 2, were generated using Guilford and Fruchter's (1978) procedure by calculating the sums of the standard scores of contributing tasks. Composite scores represent common variance across tasks that measure the same underlying construct. Because a composite score does not include task-specific sources of variance (such as measurement error), the correlation between two composite scores provides a more accurate estimate of the degree of relationship between the constructs they represent than is provided by the observed correlations between a pair of tasks. It is appropriate, however, to study the relationship of the tasks in these categories before further analysis. Prior to this analysis a test was made of the homogeneity of variance in each ability group. A Bartlett test of homogeneity was significant for automaticity tasks [X^2 (66, N=80) = 115.12, p <.05], for working memory tasks [X^2 (55, N=80) = 221.90, p < .05], and for metacognition tasks [X^2 (15, N=80) = 44.27, p < .05]. Therefore, the scores were transformed by a square root transformational process for the subsequent analyses.

Because the classification of tasks into each category was done *a priori,* four steps were involved in validating whether tasks that made up each category of process were related to each of the composite scores (computed with Z scores on the transformed scores).

The first step when analyzing composite scores is to look at the intercorrelations between the automaticity tasks, the working memory tasks, and the metacognition tasks to determine whether they reflect independent operations. The second step is to determine whether the tasks in each construct were, on average, significantly correlated. This was done by determining the mean intercorrelation of each composite using a procedure outline by Kaiser (1968). By this procedure an estimate of the average correlation in the matrix was calculated as the largest eigenvalue minus one divided by the number of variables minus one. The third step is to look at reliability of the scores when used as a composite by calculating the Cronbach Coefficient Alpha. The fourth step was to determine if there are substantial differences between the mean intercorrelations of the three composite scores.

Table 5 shows the intercorrelations between the automaticity tasks. Only two of these correlations were not significant: sound blending rate with vocabulary rate, and sound blending rate with real word rate. As can be seen from Table 5, the majority of the correlations indicate substantial relationships between the tasks. The mean intercorrelation for the automaticity composite is .49 (p < .001). Cronbach Coefficient Alpha for the standardized scores on the automaticity tasks was .92, which is a high correlation, and all intercorrelations with the total, with the exception of Sound Blending Rate, were above .55.

Table 6 shows the intercorrelations between the working memory tasks. All intercorrelations were significant, all ps < .05. As can be seen from Table 6, the majority of the correlations indicate substantial relationships between the tasks. The mean intercorrelation for the working memory composite is .54 (p < .001). Cronbach Coefficient Alpha for the standardized scores on the working memory tasks was a high .91, and all intercorrelations with the total were substantial (r >.50).

Table 7 shows the intercorrelations between the metacognitive tasks. All correlations were significant, all ps < .05. As can be seen from the table, the vast majority of the coefficients indicate substantial relationships between the tasks. The mean intercorrelation for the metacognitive composite was .51 (p < .001). Cronbach Coefficient Alpha for the standardized scores on the metacognitive tasks was .81 and all intercorrelations with the total were above .45.

Overall then, the number of significant intercorrelations and the magnitude of the coefficients support the *a priori* theoretical groupings of tasks into these process categories.

In order to determine if the mean correlation for each category (automaticity $r = .49$, metacognition $r = .51$ and working memory $r = .54$) varied significantly from each other, a transformation of the correlations using Fisher's Z (Glass & Hopkins, 1984) was done. The magnitude of the difference in Z transformations was not significant, ps $> .05$.

C. ABILITY GROUP X AGE COMPARISONS

One major purpose of the study was to determine if learning disabled readers are inferior to non-disabled readers on processes related to automaticity, metacognition, and working memory. It was also of interest to determine if these ability group differences were age-related.

A preliminary ANOVA indicated that the two groups differed significantly on IQ measures. For this reason, Raw IQ was used as a covariate in subsequent analysis. It should be noted that in the ANCOVA analysis the assumption of parallel regression lines was not violated (Glass & Hopkins, 1984). That is, the two groups had equal slopes and when IQ was covaried and the subjects' scores adjusted, both groups' scores were adjusted equally. When IQ was removed the non-disabled group moved down and the disabled group moved up, in an equally linear homogenous fashion.

1. Multivariate Analysis of Covariance

A 2 (ability) x 2 (grade) MANCOVA, across the 11 variables assumed to measure automaticity was significant for ability [Wilks' F (11,57) = 13.69, p < 0001], for grade level [Wilks' F (11,57) = 13.34, p < .0001], and for ability X grade level interaction [Wilks' F (11,57) = 4.24 p < .01]. ANCOVAs were thus computed using raw IQ scores as the covariate.

As shown in Table 8, one way ANCOVAs indicated that 10 of the 11 automaticity variables were significantly different between ability groups. Only Sound Blending Rate was comparable across ability groups. Preliminary analysis had shown that Sound Blending was different in accuracy scores across ability groups, but the non-disabled group took longer to blend the sounds and therefore the rate score was not significantly different. As shown in Table 8, ten of the eleven rate variables showed significant differences between grade levels. Only Vocabulary Rate was comparable across grade level. This is probably a result of two levels of the vocabulary test being administered. The different levels used were grade appropriate; therefore, age differences were factored out.

Learning disabled students, then, were inferior in all but one automaticity task when compared to non-disabled students and the grade threes were inferior to grade six children in all but one automaticity task. Phonemic Deletion Rate, Orthographic Choice Rate, and Real Word Rate showed significant grade level X ability interactions. Using *t* tests to investigate these interactions, the important findings were that on all three tasks, the learning disabled group improved with age but the non-disabled did not (all *p*s $< .05$). It would appear that the non-disabled group had reached a ceiling level in these tests. In general, the overall results support previous studies indicating that LD readers are inferior to non-disabled readers across a majority of low-order tasks and those differences are maintained across age.

A 2 (ability) x 2 (grade) MANCOVA across the 10 working memory variables was significant for grade [Wilks' F (10,66) = 8.36, $p < .0001$] and for ability [Wilks' F (10,66) = 6.70 $p < .0001$]. The interaction effect was not significant [Wilks' F (10,66) = 1.31, $p < .24$]. As shown in Table 9, one way ANCOVAs showed that all 10 working memory variables showed significant ability group differences and significant grade group differences. Learning disabled students were inferior to non-disabled students in all tasks of working memory. Grade six students, both learning disabled and non-disabled were superior on all working memory tasks when compared to grade three students. Learning disabled grade six students still lagged behind their grade counterparts in all working memory tasks but they did show improvement with age.

A 2 (ability) x 2 (grade) MANCOVA across the 5 variables assumed to measure metacognition was significant for ability [Wilks' F (5,71) = 11.54 p < .0001] and for grade [Wilks' F (5,71) = 14.35, p < .0001]. The interaction effect was not significant. As shown in Table 10, one way ANCOVAs indicated that all metacognitive variables showed significant ability group differences. As shown in Table 10, analyses indicated that one of the five metacognition variables did not show significant age effects, the Schema Task. Since previous research had shown improvement in the schema as a function of age, these results were unexpected. It is possible, that, like the vocabulary task above, grade appropriate levels of the task may have factored out the age effects. It is also possible that the two levels of the tasks were not equally difficult. Lack of task equivalency, then, could remove any age differences.

D. CORRELATIONS

A second purpose of this study was to look at the relationship of automaticity, working memory, and metacognition in reading for learning disabled and non-disabled students. Thus, intercorrelations were calculated between the 3 processes and KTEAS scores (standard KTEA scores). Percentile IQ was also included in the correlational analysis since its role in reading processes is under debate (e.g., Leong, 1989; Siegel, 1989a). It should be noted that the Coloured Progressive Matrices does not give standardized scores. For this reason percentiles were used in the analysis. Raw IQ scores were not appropriate in the analysis because of age factors. The reader, therefore, is cautioned when interpreting the coefficients. Table 11 shows the intercorrelations between automaticity, metacognition, IQ (percentile) and KTEAS for the entire group. As can be seen, there are significant correlations between the three processes and reading scores. All intercorrelations between the processes and reading are substantial, above .50. IQ does not correlate significantly with automaticity, but it does correlate significantly with working memory and metacognition. This correlation, although significant, indicates only a moderate relationship (coefficient > .50). Overall, the results indicate that the efficiency or automaticity of lower order skills in reading are weakly related to IQ, but these skills are highly related to a general resource (working memory) and knowledge (metacognition) system.

Table 12 shows the correlations between automaticity, metacognition, IQ (percentile), and KTEAS (standard score) as a function of ability group. For both the disabled and non-disabled groups significant intercorrelations between the three processes emerge. Thus, there is not support for the modularity hypothesis in the current sample. An interesting finding was that, in contrast to the LD group, working memory is not significantly correlated to reading for the non-disabled group. Thus, although a general resource system is related to reading and other cognitive processes in learning disabled readers, its relationship to reading in skilled readers must be qualified.

The relationship between automaticity, metacognition, and working memory as a function of age is shown in Table 13. There are significant correlations between automaticity, working memory and metacognition with each other and with reading scores at both age levels. All the intercorrelations between processing variables are above .55. Thus, generality of intercorrelations among the three processes holds across ability, as well age group.

What is the competing interpretation to the generality of the intercorrelation patterns found in the previous analysis? Previous research has shown that vocabulary plays a significant role in working memory (Baddeley et al., 1985; Dixon et al., 1988). Vocabulary Rate and age accounted for 60% of variance in predicting ability group memberships in the present study. The most logical alternative to a general working memory system is that all variables are related to word knowledge. Thus, the correlations may not be mediated by a working memory system but instead reflect a general large vocabulary ability. Therefore, partial correlations were done, removing Vocabulary Rate and Age from the analysis. Table 14 shows the intercorrelations between automaticity, metacognition, IQ (Raw), and KTEA with age and Vocabulary Rate partialled out. At the top of Table 14 the partial correlations are found for the total sample. As shown, the strong correlations among the three processes and reading are maintained, even when vocabulary is partialled out in the analysis. Thus, there is little support for the notion that correlations related to a general resource system (working memory) are isolated to the domain of language. Interestingly, IQ plays no important role in the analysis. Overall, weak support is provided for the modularity hypothesis, whereas the general resource model outlined by Turner and Engle (1989) provides an acceptable interpretation of the results. As shown at the bottom of Table 14, a within group analysis provides a different picture of the results. Because of a possible restriction in the range of scores, Spearman Rho's were used in the correlation analysis.

When comparing Table 14 and 12, four important findings within ability groups emerge. First, as shown in Table 14, working memory maintains a significant correlation with metacognition and reading for both ability groups. Second, the relationship between working memory and automaticity in both ability groups is lost when vocabulary and age are partialled out. Thus, the relationship between working memory and automaticity is mediated by word knowledge. Third, for both groups, automaticity yields higher coefficients to reading than either working memory or metacognition. Finally, automaticity is unrelated to all other processes except reading. Thus, automaticity appears to be an encapsulated process which is only related to reading. However, this interpretation must be qualified since the correlation between automaticity and working memory approached significance ($r = .29$, $p < .06$) in non-disabled readers.

Overall, the results indicate that working memory maintains a relationship to reading performance and metacognition but is independent of automaticity when an analysis occurs within subgroups.

TABLE 2
Means and Standard Deviations of Experimental Variables for Total Sample Group

	Mean	SD
Automaticity		
Phonemic Deletion-Total Correct(10)	6.67	2.95
Phonemic Deletion-Time	49.31	21.82
Phonemic Deletion-Rate	.16	.10
Sound Blending-Total Correct(30)	26.71	3.44
Sound Blending-Time	119.63	27.71
Sound Blending-Rate	.23	.06
Digit Naming-Correct(100)	99.16	1.51
Digit Naming-Time	66.82	27.99
Digit Naming-Rate	1.69	.59
Phonological Choice-Total Correct(25)	18.63	5.14
Phonological Choice-Time	123.21	40.55
Phonological Choice-Rate	.16	.06
Pseudoword Repetition-Total Correct(30)	17.53	5.24
Pseudoword Repetition-Time	74.75	6.94
Pseudoword Repetition-Rate	.23	.07
Orthographic Choice-Total Correct(25)	21.71	4.61
Orthographic Choice-Time	91.45	33.42
Orthographic Choice-Rate	.26	.10
Homophones-Total Correct(25)	19.87	3.78
Homophone-Time	115.11	36.15
Homophone-Rate	.19	.07
Semantic Choice-Total Correct(35)	31.16	3.71
Semantic Choice-Time	112.24	25.01
Semantic Choice-Rate	.29	.06
Vocabulary-Total Correct(23)	15.37	4.87
Vocabulary-Time	107.64	43.16
Vocabulary-Rate	.16	.09
Real Word Recognition-Total Correct(40)	28.31	13.04
Real Word Recognition-Time	75.18	59.49
Real Word Recognition-Rate	.62	.43
Phonological Words-Total Correct(40)	21.47	13.04
Phonological Words-Time	105.48	69.19
Phonological Words-Rate	.31	.27
Working Memory		
Sentence Span-Total Correct(8)	1.07	1.26
Counting Span-Total Correct(15)	8.85	2.38
Visual Spatial Shading-Total Correct(20)	10.33	4.27
Visual Spatial Mr. Cucumber-Total Correct(18)	9.21	3.00
Concurrent Memory-Digit-Blanks-Total Correct(4)	.98	1.32
Concurrent Memory-Digit-Categories-Total Correct(4)	.61	1.09
Concurrent Memory-Digit-Shapes-Total Correct(4)	.56	1.07
Concurrent Memory-Colour-Blanks-Total Correct(4)	.45	.85
Concurrent Memory-Colour-Categories-Total Correct(4)	.55	.85
Concurrent Memory-Colour-Shapes-Total Correct(4)	.58	.97
Metacognition		
Metacognitive Questionnaire(80)	56.81	7.30
Cloze Exercise-Syntax Score(14)	8.48	3.49
Cloze Exercise-Semantic Score(14)	8.00	3.36
Inconsistencies-(6)	1.27	1.81
Use of Schema-Total Score(18)	10.73	3.59

Table 3
Factor Solution with Varimax Rotation

	1	2	3	4	5
1. Phonemic Rate	.65				
2. Sound Blending Rate				.81	
3. Digit Naming Rate	.83				
4. Phonological Choice Rate	.52				
5. Pseudoword repetition Rate				.61	
6. Orthographic choice Rate	.85				
7. Homophones Rate	.75				
8. Semantic Categories Rate	.61				
9. Vocabulary Rate	.51				
10 Real Word Recognition Rate	.88				
11 Phonemic Words Rate	.76				
12 Sentence Span		.36			
13 Counting Span		.38			
14 Visual Spatial Shading		.55			
15 Visual Spatial (Mr.Cucumber)	.51				
16.Concurrent Memory Digit Blank		.65			
17.Concurrent Memory Digit Categories		.74			
18.Concurrent Memory Digit Shapes		.79			
19.Concurrent Memory Colour Blank		.64			
20.Concurrent Memory Colour Categories		.76			
21.Concurrent Memory Colour Shapes		.78			
22.Metacognitive Questionnaire					.38
23.Syntax Score			.71		
24.Semantic Score			.70		
25.Inconsistencies			.45		
26.Schema			.83		
Eigenvalue	11.91	1.96	1.55	1.28	1.08

TABLE 4
Means and Standard Deviations of Experimental Variables as a Function of Ability Groups

Variables	Normal		L.D.	
	Mean	SD	Mean	SD
Phonemic Deletion-Rate	.22	.09	.11	.09
Sound Blending-Rate	.23	.06	.23	.07
Digit Naming-Rate	1.98	.58	1.41	.45
Phonological Choice-Rate	.18	.07	.15	.06
Pseudoword Repetition-Rate	.26	.05	.20	.07
Orthographic Choice-Rate	.31	.09	.21	.10
Homophone-Rate	.23	.07	.15	.05
Semantic Choice-Rate	.30	.06	.27	.06
Vocabulary-Rate	.22	.08	.11	.05
Real Word Recognition-Rate	.87	.37	.37	.34
Phonological Words-Rate	.47	.27	.14	.13
Sentence Span-Total Correct	1.72	1.28	.42	.84
Counting Span-Total Correct	9.77	2.43	7.92	1.95
Visual Spatial Shading-Total Correct	11.80	4.18	8.87	3.89
Visual Spatial Mr. Cucumber-Total Correct	10.96	3.36	8.46	2.28
Concurrent Memory-Digit-Blanks-Total Correct	1.62	1.42	.35	.83
Concurrent Memory-Digit-Categories-Total Correct	1.10	1.33	.12	.40
Concurrent Memory-Digit-Shapes-Total Correct	1.07	1.32	.05	.22
Concurrent Memory-Colour-Blanks-Total Correct	.80	1.06	.10	.30
Concurrent Memory-Colour-Categories-Total Correct	.95	.95	.15	.48
Concurrent Memory-Colour-Shapes-Total Correct	1.05	1.15	.12	.40
Metacognitive Questionnaire	59.30	7.00	54.32	6.81
Cloze Exercise-Syntax Score	10.27	3.42	6.70	2.53
Cloze Exercise-Semantic Score	9.72	2.81	6.27	2.96
Inconsistencies-	1.90	1.56	.37	.77
Use of Schema-Total Score	12.12	3.03	9.35	3.59

Table 5 - Means and Standard Deviations of Experimental Variables as a Function of Ability and Grade

Grade	Normal		LD	
	Mean	SD	Mean	SD
Phonemic Deletion-Rate	.16	.06	.03	.02
Sound Blending-Rate	.19	.04	.21	.05
Digit Naming-Rate	1.56	.32	1.12	.33
Phonological Choice-Rate	.13	.04	.12	.03
Pseudoword Repetition Rate	.23	.04	.18	.06
Orthographic Choice-Rate	.25	.07	.14	.05
Homophone-Rate	.17	.05	.11	.04
Semantic Choice-Rate	.26	.05	.23	.05
Vocabulary-Rate	.20	.07	.10	.05
Real Word Recognition-Rate	.63	.28	.13	.19
Phonological Word-Rate	.29	.24	.06	.08
Sentence Span	1.00	1.02	.15	.48
Counting Span	8.30	1.71	6.80	1.50
Spatial (Shading)	9.20	3.69	6.45	2.18
Visual Spatial (Mr.Cucumber)	8.64	3.15	6.90	4.32
Concurrent Memory-Digit-Blank	.95	1.14	.05	.22
Concurrent Memory-Digit-Categories	.45	.82	.00	.00
Concurrent Memory-Digit-Shapes	.50	.88	.00	.00
Concurrent Memory-Colour-Blank	.35	.48	.05	.22
Concurrent memory-Colour-Categories	.45	.68	.05	.22
Concurrent Memory-Colour-Shapes	.60	.68	.05	.22
Metacognitive Questionnaire	54.60	5.34	50.90	4.35
Cloze-Syntax	9.45	4.31	5.85	2.49
Cloze-Semantic	8.25	2.63	4.85	2.27
Inconsistencies	1.30	1.17	.10	.44
Schema	12.00	3.43	9.90	2.82

Grade 6	Normal		SD	
	Mean	SD	Mean	LD
Phonemic Deletion-Rate	.28	.08	.19	.06
Sound Blending-Rate	.28	.04	.25	.08
Digit Naming-Rate	2.39	.49	1.70	.37
Phonological Choice-Rate	.23	.05	.17	.07
Pseudoword Repetition Rate	.30	.04	.23	.07
Orthographic Choice-Rate	.38	.05	.29	.07
Homophone-Rate	.28	.05	.19	.03
Semantic Choice-Rate	.34	.03	.31	.05
Vocabulary-Rate	.24	.09	.12	.05
Real Word Recognition-Rate	1.11	.28	.61	.29
Phonological Word-Rate	.64	.17	.22	.12
Sentence Span	2.45	1.09	.70	1.03
Counting Span	11.25	2.14	9.05	1.70
Visual Spatial (Shading)	14.40	2.83	11.30	3.74
Visual Spatial (Mr.Cucumber)	11.24	3.12	10.05	2.10
Concurrent Memory-Digit-Blank	2.30	1.38	.65	1.08
Concurrent Memory-Digit-Categories	1.75	1.44	.25	.55
Concurrent Memory-Digit-Shapes	1.65	1.46	.10	.30
Concurrent Memory-Colour-Blank	1.25	1.29	.15	.36
Concurrent memory-Colour-Categories	1.45	.94	.25	.63
Concurrent Memory-Colour-Shapes	1.50	1.35	.20	.52
Metacognitive Questionnaire	64.00	5.05	57.75	7.18
Cloze-Syntax	11.10	2.02	7.55	2.32
Cloze-Semantic	11.20	2.19	7.70	2.93
Inconsistencies	2.50	1.70	.65	.93
Schema	12.25	2.67	8.80	4.23

Table 6
Correlations between Rate Variables

	1	2	3	4	5	6	7	8	9	10	11
Phonemic Deletion Rate											
Sound Blending Rate	.34****										
Digit Naming Rate	.70****	.29**									
Phonological Choice Rate	.49****	.48****	.48****								
Pseudoword Repetition Rate	.53****	.44****	.32**	.53****							
Orthographic Choice Rate	.72****	.24*	.75****	.49****	.33**						
Homophone Rate	.72****	.37***	.70****	.53****	.44****	.81****					
Semantic Choice Rate	.62****	.31**	.59****	.32**	.34***	.53****	.60****				
Vocabulary Rate	.46***	.10	.50****	.38***	.44***	.53****	.54****	.38***			
Real Word Rate	.74****	.16	.76****	.50****	.41***	.87****	.75****	.59****	.63****		
Phonological Word Rate	.75****	.26*	.77****	.50****	.44****	.70****	.69****	.59****	.54****	.79****	
Mean	.38	.47	1.27	.39	.47	.50	.42	.53	.38	.70	.47
SD	.14	.07	.21	.07	.08	.10	.08	.06	.11	.33	.26

** p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 7
Correlations between the Working Memory Variables

	1	2	3	4	5	6	7	8	9	10
Sentence Span										
Counting Span	.48****									
Visual Spatial (Shading)	.57****	.59****								
Visual Spatial (Mr. Cucumber)	.31**	.45***	.61****							
Concurrent Digit Blank	.50****	.54****	.51****	.37***						
Concurrent Digit Categories	.49****	.54****	.56****	.38***	.69****					
Concurrent Digit Shapes	.46****	.55****	.47***	.36***	.64****	.70****				
.Concurrent Colour Blank	.27**	.37***	.37***	.37***	.44****	.58****	.55****			
Concurrent Colour Categories	.55****	.51****	.53****	.24*	.55****	.64****	.68****	.57****		
.Concurrent Colour Shapes	.35***	.56****	.46****	.27**	.50***	.47****	.66****	.66****	.64****	
Mean	.71	2.94	3.14	1.72	.64	.42	.37	.35	.42	.43
SD	.75	.40	.69	.29	.76	.66	.65	.57	.60	.63

* *p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 8
Correlations between Metacognitive Variables

	1	2	3	4	5
1. Questionnaire					
2. Cloze (Syntax)	.35**				
3. Cloze (Semantic)	.47****	.92****			
4. Inconsistencies	.33**	.62****	.55***		
5. Schema	.32**	.40****	.40****	.35***	
Mean	7.52	2.83	2.73	.76	3.20
SD	.48	.66	.71	.83	.69

* *p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 9
Univariate Analysis for Automaticity Tasks

	Ability F (4,67)	Grade F(4,67)	Ability X Grade Interaction F (4,67)
Phonemic Deletion Rate	67.41****	67.35****	14.29
Sound Blending Rate	.01	8.24**	ns
Digit Naming Rate	28.19****	39.18****	ns
Phonological Choice Rate	7.94**	33.76****	ns
Pseudoword Rate	21.49****	19.12****	ns
Orthographic Choice Rate	44.86****	67.02****	5.88
Homophone Choice Rate	54.01****	72.81****	ns
Semantic Choice Rate	6.88**	20.74****	ns
Vocabulary Rate	50.37****	3.28	ns
Real Word Rate	67.03****	47.16****	5.44
Phonological Word Rate	55.39****	39.06****	ns

* *p*<.05, ***p*<.01, ****p*<.001, *****p*<.0001

Table 10
Univariate Analysis of Working Memory Tasks

	Ability F(4,75)	Grade F(4,75)
Sentence Span	36.09***	15.27***
Counting Span	18.71****	37.67****
Visual Spatial (Shading)	13.65***	43.77***
Visual Spatial (Mr.Cucumber)	5.92**	25.94****
Concurrent Memory(Digit-Blank)	35.26****	19.16****
Concurrent Memory (Digit-Category)	26.62****	16.14****
Concurrent Memory (Digit-Shape)	31.09***	10.48***
Concurrent Memory (Colour-Blank)	18.54****	6.12**
Concurrent Memory (Colour-Category)	32.64****	14.81***
Concurrent Memory (Colour-Shape)	27.13****	4.26*

* $p<.05$, ** $p<.01$, *** $p<.001$, **** $p<.0001$

Table 11
Univariate Analysis of Metacognition Tasks

	Ability F (4,75)	Grade F (4,75)
Metacognitive Questionnaire	16.19****	41.42****
Cloze (Syntax)	24.84****	7.30**.
Cloze (Semantic)	26.83****	18.72***
Inconsistencies	38.32****	4.72*
Schema	15.63***	.01

* *p*<.05, ***p*<.01, ****p*<.001, *****p*<.0001

Table 12
Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEAS for the Entire Sample

	Automaticity	Working Memory	Metacognition	IQ	KTEAS
Automaticity	.-----				
Working Memory	.72****	.----			
Metacognition	.65****	.71****	.----		
IQ (Percentile)	.18	.30**	.36**	.----	
KTEAS	.66****	.58****	.67***	.39***	.-----

** p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 13
Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEAS for the Non-Disabled Group

	Automaticity	Working Memory	Metacognition	IQ	KTEAS
Automaticity	.------				
Working Memory	.58***	.-----			
Metacognition	.52***	.57***	.-----		
IQ	-.14	.12	.09	.----	
KTEAS	.44**	.21	.50***	.26	------

Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEAS for the Disabled Group

	Automaticity	Working Memory	Metacognition	IQ	KTEAS
Automaticity	.-----				
Working Memory	.64***	.------			
Metacognition	.42**	.59****	.------		
IQ	.11	.19	.34*	.----	
KTEAS	.50***	.37**	.39**	.24	------

** p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 14
Correlations between Automaticity, Working Memory, Metacognition, and KTEA scores for Grade 3

	Automaticity	Working Memory	Metacognition	IQ	KTEA
Automaticity	.------				
Working Memory	.59***	.------			
Metacognition	.65***	.64***	.-----		
IQ	.03	.19	.02		
KTEA	.90****	.64****	.72****	.02	.---

Correlations between Automaticity, Working Memory, Metacognition, and KTEA scores for Grade 6

	Automaticity	Working Memory	Metacognition	IQ	KTEA
Automaticity	.----				
Working Memory	.65***	.-----			
Metacognition	.58***	.71****	.-----		
IQ	.05	.32	.27	.----	
KTEA	.82****	.74****	.71****	.18	.----

** p<.05, **p<.01, ***p<.001, ****p<.0001*

Table 15

Pearson Product Moment Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEA for total sample with age and Vocabulary Rate partialled out

	Automaticity	Working	Metacognition	IQ	KTEA
Automaticity	.----				
Working Memory	.49****		.-----		
Metacognition	.42***	.55****	.-----		
IQ	-.04	.11	-.04	.-----	
KTEA	.83****	.55****	.56****	-.04	.----

Spearman Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEA for the Non-Disabled Group with age and Vocabulary Rate partialled out.

	Automaticity	Working Memory	Metacognition	IQ	KTEA
Automaticity	.------				
Working Memory	.29	.-----			
Metacognition	.25	.45**	.-----		
IQ	-.10	.23	.04	.----	
KTEA	.70***	.34*	.39**	.04	------

Spearman Correlations between Automaticity, Working Memory, Metacognition, IQ and KTEA for the Disabled Group with age and Vocabulary Rate partialled out.

	Automaticity	Working Memory	Metacognition	IQ	KTEA
Automaticity	.-----				
Working Memory	.18	.------			
Metacognition	.17	.48**	.------		
IQ	.05	.11	.30	.----	
KTEA	.76***	.34*	.29	.23	------

** p<.05, **p<.01, ***p<.001, ****p<.0001*

V. DISCUSSION

A. ANALYSIS

One purpose of this study was to compare learning disabled and non-disabled readers' performance on tasks which reflect automaticity, working memory, and metacognition as a function of age level. The general findings were that the two groups (both age and ability) differ significantly on all three processing tasks. It was also the purpose of this study to compare the intercorrelational patterns of learning disabled and non-disabled youngsters on these three processes. The results indicate a significant relationship between automaticity, working memory, and metacognition for the total sample, and both the LD and non-disabled group. This intercorrelational pattern was qualified, however, when vocabulary was partialled out in the analysis. Although the strong intercorrelation patterns occurred for the total sample, the relationship between working memory and automaticity was weakened within ability groups. Both working memory and automaticity maintained a significant correlation with reading. Results provide support for the notion that a general working memory is related to reading ability, as well as the fact that automatic processes operate as encapsulated "operations" only when word knowledge is partialled out in the analysis. This pattern held true for both learning disabled and non-disabled readers. Overall, the results suggest that a general resource system plays a major role in accounting for ability group differences. This general resource system maintains significant correlations to other processes and reading, especially when vocabulary ability is left to covary in the analysis.

Results will be discussed in relation to each of the processing categories and correlational patterns and then be placed within the context of the current literature. The results will then be summarized as they addressed each hypothesis.

1. Automaticity Tasks

Each child was administered 11 lower order reading tasks. As was expected, the majority of these tasks yielded rate performance differences between ability groups. The only task that did not was the Sound Blending Rate task. This task showed age improvement, but not ability group differences. There are plausible reasons why ability differences were not found on this task. Preliminary analysis indicated that Sound Blending accuracy was significantly different for ability groups, but it took the control group longer to produce the correct blends and, therefore, the rate for correct answers was not significantly different.

Ten of the 11 lower order reading tasks yielded age differences, that is students improved on all tasks as they got older. Vocabulary Rate task was comparable across ages. This would be expected as the vocabulary task was grade appropriate. Three tasks showed age/ability interaction. Phonemic Word Rate, Orthographic Choice Rate, and Real Word Rate showed an interaction effect and it is, therefore, not applicable to state that all students showed age and ability differences on these tasks. T-tests on individual means indicated that the non-disabled group did not make significant gains whereas the disabled group did.

2. Working Memory Tasks

Each child was administered 10 working memory tasks. All working memory tasks showed age and ability differences. Moreover, all working memory tasks were significantly correlated (as shown in Table 6) with a mean intercorrelation $r = .49$, $p < .001$. This high intercorrelation among diverse working memory tasks supports the work of Turner and Engle (1989) and Swanson (1992) which suggested that diverse working memory measures which include both verbal and visual-spatial operations are significantly correlated. That is, children who score high (or low) on verbal working memory measures also score high (or low) on visual-spatial measures. These correlations lend support to the "task independent theory" of working memory (Engle et al., 1992; Turner & Engle, 1989; Swanson, 1992). In this theory, the student's reading score is tied to his or her general working memory ability. In contrast, the task independent theory (Daneman, 1982), assumes that the student's reading score is tied to working memory tasks only when the working memory task requires the subject to use the same reading-specific processes as are contained in the reading measure. In the present study, regardless of whether the working memory task involved verbal, non-verbal, or spatial processing, all the working memory tasks were significantly correlated to each other and to reading. This supports Turner and Engle's (1989) notion that people are good readers because they have larger general working memory. Turner and Engle reasoned that if significant correlations emerged from working memory measures which did not include reading process, then one could conclude that the relationship between working memory and reading comprehension is independent of the specific skills which are involved in the secondary task. Such was the case in their findings (Engle et al., 1992; Turner & Engle, 1989) and in the present study.

3. Metacognition

Each child was administered 5 metacognitive tasks. All the tasks showed ability group differences, and all but the Schema Task showed age differences. Since previous research has shown improvement as a function of age (Ohlhausen & Roller, 1988) the present results were unexpected. One possible explanation for the failure to find age differences on the Schema Task was the inequality between the difficulty levels of the passages. The paragraphs were grade appropriate therefore partialling out any unique variance related to age.

4. Correlational Patterns

A major purpose of this study was to examine the relationship between automaticity, working memory and metacognition in learning disabled and non-disabled readers. The reason for the investigation of the correlational patterns was to compare two frameworks to understand ability group differences in reading.

Let us consider the two frameworks in reference to the present results.

a. General capacity model versus modularity model

The correlational patterns for automaticity, metacognition, and working memory are similar for both disabled and non-disabled readers. That is, there is a strong, significant correlation between all three processes in both ability groups and those strong correlations are maintained at two different age levels. What process mediates these correlations? It was hypothesized that if a significant relationship was found between the three constructs, a general working memory system may mediate the correlations. Implicit in this model is the concept of a central executive responsible for the control and organizing of processes related to reading. It was hypothesized, on the other hand, that if cognitive processes operate independently of one another, yet predict reading, a weak relationship would be found between working memory, automaticity, and metacognition. Although the modularity argument has been traditionally applied to lower order skills and a general resource system, the generality of the modularity argument was tested between working memory and metacognition. Implicit in this argument is that working memory, automaticity, and metacognition are related to reading in and of themselves but not because of any common central control. In the present study, significant correlations between the three constructs were found for the total sample, within the age groups and within the two ability groups. Thus support is found for the general resource capacity model. That is, support was found for the idea of a central executive control being a common factor underlying the three constructs.

However, it could be argued that the significant relationship between the three constructs was the result of an undetected reading-related variable common to all three constructs. In looking for this common factor the literature has questioned whether working memory is really any different from word knowledge (Engle et al., 1990). Further, vocabulary rate and age were the largest contributors to predicting ability group membership in this study. It is possible, then, that vocabulary is that common underlying reading-related variable in this study. Therefore, vocabulary rate and age were partialled out of the correlation. The significant correlation between metacognition and working memory remained in both ability groups even with word knowledge and age partialled out. The correlation between automaticity and working memory, while no long significant, is approaching significance in the non-disabled group. Further, the fact that strong intercorrelations were found in the total sample, but not with groups, most likely reflects some restrictions in range in the scores at the ability group level. Overall, the results indicate support for the theory of a general resource capacity even when word knowledge is removed from the analysis. Automaticity may act independently of other processes, but the independence emerges only when word knowledge is partialled out of the results.

b. Compensatory strategies of metacognition versus necessity of lower level skills

There is a flip-side to the interpretation. Analyzing the correlational patterns of automaticity, working memory, and metacognition also addresses an interesting question. That is, given that a positive relationship exists between lower order skills (automaticity) and higher levels skills (working memory/metacognition) within a language system, is the automaticity of lower order reading skills necessary to "free space" for higher level processing? It would appear that the pattern for both the disabled and the non-disabled reader was similar. In both groups strong correlations were found between automaticity, metacognition, and working memory. This lends support to the concept that automaticity of lower order skills may be necessary to free space for high level processing at least within a language or reading domain. The finding also lends support to Perfetti's theory (outlined in Chapter II) of verbal efficiency, whereby high efficiency lexical access and other low level skills leave resources free for high level skills such as making inferences and critical comprehension.

The results may also be considered in relation to the recent work of Walczyk (1993). Walczyk (1993) found that when readers controlled their reading rate, they compensated for subcomponent inefficiency and therefore reading was weakly correlated with low-order processing. In Experiment 1, Walczyk (1993) had the students read at their own rate and then answer comprehension questions. He found weak correlations between students' rate on selected reading subcomponents and high-level inferencing questions. Coefficients ranged between .03 and .37. In Experiment 2, the students read at a controlled rate which did not allow for the slowing down, rereading processes that would compensate for decoding inefficiency.

The results of this study showed that students with less efficient decoding scored lower on the comprehension questions in the second part of the study when they were not allowed to "compensate" for their inefficient subcomponents by slowing down. Correlations between rate of reading subcomponents and high level inferencing now ranged between .44 and .50. Walczyk concludes that his work supports a compensatory encoding theory of reading. The basic assumptions of this theory are that reading involves the concurrent execution of several subcomponent processes arranged hierarchically. Several individual differences exist in the efficiency of subcomponent processes and. under certain task conditions, inefficiency in a subcomponent can hamper performance by drawing attention and working memory resources away from attention-demanding activities (e.g., making inferences).

There are several differences in the present study and that of Walczyk which would account for the present study's different findings. In the work of Walczyk the students were university students and it can be surmised they had attained a high level of reading ability. In the present study the students were from grade three and grade six and included learning disabled children. Walczyk, in his work, limits his findings to "students beyond a certain level of skill development". It can be reasoned that many of the students in the present study had not yet reached that "certain level". A second possibility for the differences in the findings could be due to the fact that in the present study the metacognitive tasks were read to the students. Although they had the work in front of the them and the examiner read the work as many times as they requested, it is possible the "compensatory" strategies, when applied through another, are not as successful as when performed by the individual.

5. Prediction of Ability Group (Task Level)

The secondary purpose of the study was to ascertain which task best predicted ability group. By performing a discriminant analysis, it was ascertained that the task that best indicated whether the student was non-disabled or disabled was Vocabulary Word Rate. This task accounted for 42% of the variance between the two groups. Phonemic Deletion Rate was the second best predictor producing a significant 26% of the variance. Age was the third best producing a significant 18% of the variance. Inconsistencies produced 17%, Concurrent Memory Colour-Blank produced 10%, Sentence Span produced 6%, and Real Word Recognition Rate produced 5% of the variance. The first two of these variables are lower order skills and lend support to the theory that highly practised, automated processes are the best places to look for differences in reading ability (Stanovich, 1980). The present study, at the task level, supports the assumption that the degree to which lower order skills have become automatic is reflected in better reading because automatic processes free cognitive capacity for comprehension processes (Schwartz, 1984). It supports the concept that highly automated subprocesses are required for skilled reading (Gough, 1972; LaBerge & Samuels, 1974; Lesgold & Perfetti, 1981; Walczyk, 1993). Preliminary analysis had shown that vocabulary rate was significantly correlated to working memory scores. The substantial relationship between vocabulary rate and working memory scores supports the findings of Dixon et al. (1988) who found that word knowledge correlated with comprehension as well as working memory.

6. Relationship to IQ

The differences between the learning disabled and non-disabled students' performance on working memory tasks occurred, even when IQ was covaried. This suggests that working memory is tapping something other than "g" and is in agreement with many current findings (Crammond, 1992; Globerson, 1985; Porath, 1992; Siegel & Ryan, 1989; Swanson, 1989). A cautionary note, however, is offered regarding IQ in the Limitation section of this paper.

The discussion section has addressed the hypotheses, but for purposes of clarity they are presented now with a summary statement of the findings.

B. HYPOTHESES

1. *LD readers will score significantly lower on measures of working memory than non-disabled readers.*

This was supported. Learning disabled readers were inferior to non disabled readers on all working memory tasks.

2. *LD readers will score significantly lower on measures of automaticity than non-disabled readers.*

This was supported. Learning disabled readers were inferior on 10 of the 11 rate variables. The only task in which there were not ability group difference was Sound Blending. Sound Blending accuracy scores were significantly different, but the non-disabled students took longer to blend, and therefore, the rate score was not significantly different.

3. *LD readers will score significantly lower on measures of metacognition than non-disabled readers.*

This was supported. Learning disabled readers were inferior on all 5 metacognitive tasks.

4. *Scores of working memory will increase developmentally.*

This was supported. Grade 3 students were inferior to grade 6 students on all working memory tasks.

5. *Scores of automaticity will increase developmentally.*

This was supported. Grade three students were inferior in 10 of the 11 rate variables. Only Vocabulary Rate was comparable across grades, probably due to the administration of grade appropriate vocabulary tasks. However, there were interaction effects for Phonemic Deletion Rate, Orthographic Choice Rate, and Real Word Rate. T-tests indicated that the non-disabled group did not show significant developmental improvement on these tasks whereas the disabled group did. It would appear that a plateau effect occurred.

6. *Scores of metacognition will increase developmentally.*

This was supported in all but one of the metacognitive variables--the schema task. Lack of task difficulty equivalency was offered as a possible reason for this.

7. i) Significant correlations between working memory, automaticity of lower order skills, and metacognition would lend support to the resource capacity model. Non-significant correlations between working memory, automaticity of lower order skills, and metacognition would support the modularity theory.

ii) Since the individual tasks within the constructs change developmentally the overall correlational pattern may change developmentally. The correlational patterns will be looked at in grade three and grade six groups.

iii) It could be argued that LD readers are deficient in all three major processes, the intercorrelation among these three processes may be different from their average counterparts. The intercorrelational pattern will be compared in LD and non-disabled groups.

The results indicate that working memory was strongly correlated to automaticity and metacognition for the entire group as well as for the learning disabled and non disabled groups, lending support to the general resource capacity theory. Even when vocabulary rate and age were partialled out significant correlations between working memory and metacognition were found and the relationship of working memory and automaticity was approaching significance.

The correlational pattern remained similar for the two different age groups measured. However, the relationship of automaticity to reading was not as strong for the older group. Further, the correlation between working memory and grade six reading was stronger than the relationship between working memory and grade three reading.

C. CONCLUSIONS

The results of the study support research findings that indicate that automaticity, working memory, and metacognition all play significant roles in the differences found in reading ability. The learning disabled groups differed significantly in all tasks except sound blending rate, when compared to non-disabled. Further, the study indicates that there is developmental improvement in performance. The only tasks that did not show developmental improvement were in all likelihood because of the inequality in tasks or, in the case of automaticity tasks, a plateau effect occurred. The fact that automaticity, working memory, and metacognition are all significantly intercorrelated in this study, in the non-disabled and LD group as well as at both age levels studied, lends support to the general resource capacity model.

D. LIMITATIONS

1. Size

The relatively small sample size warrants cautionary acceptance of results at the individual task level. However, the sample size does warrant acceptance of the results of the tasks when grouped in the constructs of automaticity, metacognition, and working memory. The fact that the tasks were chosen from the literature and the significant intercorrelations between the tasks in each construct warrant this.

2. Speed

A second limitation in the study is the concept of speed. It can be argued that if you are measuring speed the instructions to the students should include a direction such as "go as fast as you can". Walczyk (1993) indicated that a corollary of compensatory-encoding theory is that resource linkages (competition for limited general resources) between subcomponents and inferential comprehension processes are expected as pressure (through speed) is placed on performance. It can be assumed that a sense of pressure was not felt in the present study as the words "go as fast as you can " were not used for all the automaticity tasks.

The reason for not having the instructions say "go as fast as you can" was due to the concern expressed by the educators involved with the learning disabled group. These educators did not want the disabled youngsters to suffer any anxiety due to this research project. It was felt that induced speed could cause anxiety.

It can be argued, however, that what was lost in not placing a sense of pressure and thereby perhaps gaining a need for efficiency in the non-disabled groups, was balanced by the lack of anxiety and thereby perhaps gaining a sense of efficiency in the disabled group.

Studies have shown that speed can cause anxiety and that anxious students tend to make three times as many errors when there is a time limit than when there is not (Hill & Eaton, 1977; Woolfolk, 1990). Further, Fencham, Hokada, and Sander (1989) showed that test anxiety increases with age. In order to maximize the success of the learning disabled students by reducing the anxiety, the task instructions did not include the "as fast as you can" wording. For consistency the instructions on the digit naming task should not have contained reference to "as fast as you can". This had been included because of replicating the instructions used in preceding administrations. It was by good luck, rather than good management, that all the students felt confident about saying individual numbers. It is thought that anxiety did not become a factor in this test.

3. IQ

A third limitation of the study was the difference in IQ between the two groups. Although the non-disabled group was chosen randomly, there was the element of "volunteering" once the initial request was made. It would appear that slightly above-average students "volunteered" and thus IQ differences occurred. The Ravens Coloured Matrices was used as a covariate and the assumptions of covariance were met using this instrument. However, it can be argued that the use of a nonverbal IQ test in a study of reading is perhaps not the most appropriate assessment tool to use. The use of a verbal IQ measure could be considered in future research. In fact, given the current controversy concerning IQ measures and identification of learning disabilities (Leong, 1989; Siegel, 1989a; Swanson, 1991) it would be appropriate to use a number of IQ measures.

4. Tasks

The individual tasks used were taken from existing literature. It was not the purpose of the paper to critique or improve on these tasks but rather to use them (as accepted measures of specific reading variables) and investigate the relationship of the constructs of which they were a part. This does not imply that the tasks could not be improved upon, simply that this was not the focus of the paper.

E. FUTURE RESEARCH

The results of this study support previous research (e.g., Siegel & Ryan, 1989; Swanson et al., 1989) which indicates that working memory plays an important role in the reading differences in learning disabled children. Future research may focus on the modifiability of working memory and the subsequent development of educational programs which develop strategies to foster working memory in learning disabled youngsters.

Assessment of modifiability can take the form of systematic probes (Swanson, 1992) or dynamic assessment methods like Feuerstein's (1979). Educational programmes could take the approach of Feuerstein's Instrumental Enrichment (Feuerstein & Hoffman, 1980). Careful assessment is needed of such programmes to see if they indeed impact on reading.

VI. REFERENCES

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APPENDIX A

LETTER TO PARENTS INVITING THEIR PARTICIPATION AND SIGNED CONSENT IN THE STUDY

Dear ____________

As part of a doctoral dissertation in the Department of Educational Psychology at U.B.C., the relationship between memory and reading skills is being studied. Your school has agreed to participate in this study entitled "Working Memory and the Development of Skill in Reading". This project has been approved by the Vancouver School Board and by your school principal.

The project involves the cooperation of 80 students in the Vancouver School District and involves the use of individual cognitive test, reading tests, and memory tests.

The research seeks to discover the relationship of memory to low order reading skills (such as decoding) and higher level reading skills (such as inferencing). The project will compare reading and working memory skills of children in Grade Three and Grade Six who are enrolled in regular classroom settings and those children who are receiving extra help for reading difficulties.

_________was chosen as a possible participant. If you and your child agree to participate, _________will be asked to take part in two individual testing sessions, approximately 45 minutes in length. A trained psychologist will do the testing, using tests that are similar to ones commonly administered in schools and which children usually enjoy doing.

The results of these tests are strictly confidential. No individual test results will be released. The purpose of the project is not to test any one child's performance but to discover the possible group difference in working memory skills between average readers and those experiencing difficulties. Project results will provide useful information for professional individuals in the teaching of reading.

Parents interested in receiving a copy of group results should request this on the consent form.

I wish to emphasize that participation in this project is voluntary. Withdrawal from the project at any time will not jeopardize your child's class standing. I would, however, greatly appreciate your agreement to help.

Please complete the Parent Consent form and return it to the school as soon as possible.

Please feel free to contact me for any further information at 228-1579.

Sincerely

____

Joy Alexander
Doctoral Candidate
Dept. of Educational Psychology and Special Ed.
The University of British Columbia

____

Dr. H.L. Swanson
Professor
School of Education
University of California, Riverside

THE RELATIONSHIP OF AUTOMATICITY , WORKING MEMORY AND METACOGNITION IN NORMAL AND LEARNING DISABLED READERS
PARENT CONSENT FORM

I have received and read the attached information letter regarding the study "Working Memory and Development of Skill in Reading"

I do ______ or do not_______ grant permission for my child to participate in this project. I am aware that my child will be tested by a qualified examiner in two sessions totalling approximately 1 1/2 hours. I understand that confidentiality of the results will be maintained and that no individual scores will be released. I also understand that participation in this project is voluntary and may be terminated at any time.

Signature___________________
Relationship to child________________

I would like a copy of the results mailed to:

____
____
____

Thank you for your consideration,

____
Joy Alexander
Doctoral Candidate
Dept. of Educational Psychology and Special Ed
The University of British Columbia

____
Dr. H.L. Swanson
Professor
School of Education
University of California, Riverside

APPENDIX B

INSTRUCTIONS AND ITEMS OF TESTS

Test One
Phonemic Deletion

Instructions: I am going to say some words to you. I want you to listen carefully to the sound at the beginning of each word and then I want you to remove the starting sound from the word and then say the remaining sound segment out loud. For example if I were to say spark, you would say park. You would remove the first sound "s" from the word and tell me the sound segment that remains. Let's try another word for practice - block. Remove the starting sound and tell me what you have left. (Correction given). Let's try another for practice - the word is grab. Remove the first sound, and tell me what is left. (Correction given). Let's try one more for practice - crown. What would you say. (Correction given). Now I will say more words. Each time I want you to remove the first sound and tell me what is left.

smart
globe
spark
crib
strip
spot
trick
snipe
smack
stop

Test Two
Roswell-Chall Sound Blending Task

Instructions: We are going to do some things with words and sounds. I will say the sound in the words slowly and then you will tell me what the words are. Let us try this one. The first word is s-ing. (Sound the word clearly as indicated. Give the sounds at the rate of about one half second for each sound. Avoid inserting extraneous sounds at the end of the separate consonants). What word did I sound? Yes the word was sing. (Proceed with the other sample words: t-op, and s-i-t. At the point where the student has difficulty or pronounces the word incorrectly, stop, and illustrate how the separate sounds may be blended together to form a whole word. If 1 of the 3 examples is correct begin test, if not give two more examples and then begin regardless of whether the child is right or not. The practice words are: win met).

The word was repeated if the child requested it but the extra time was calculated in the rate score.

1. a-t	11. st-ep	21. c-a-t
2. n-o	12. f-a-t	22. b-i-g

3. i-f	13. pl-ay	23. c-u-ff
4. u-p	14. b-oat	24. s-a-d
5. s-ay	15. ch-ain	25. g-o-t
6. m-y	16. b-ed	26. m-a-p
7. b-e	17. c-ake	27. r-u-g
8. t-oo	18. r-an	28. d-e-sk
9. c-ow	19. t-ime	29. t-oa-st
10. h-e	20. c-all	30. p-e-t

.

Test Three
Digit Naming Sped

Instructions: I am going to give you a page with numbers written on it. I want you, when I turn the page over, to say all the numbers as quickly as you can from left to right. Do you understand ? Ready? Begin.

(After the child has done one page)

Now I am going to present you with a second page with numbers written on it. I want you, when I turn the page over, to say all the numbers as quickly as you can from left to right. Do you understand? Ready? Begin.

(The child was presented with a card with fifty digits, typed in Courier 12 type as follows:

26543 13689 48963 18954 98452 14238 32869 21895 43519 23169
45218 23165 34216 54689 23132 89563 23189 94314 39841 45286

Test Four
Phonological Choice

Instructions: You are going to be presented with a card with two words on it. One of the words, although it is not spelled correctly, if you pronounce it the way it is written, is a real word. I want you to tell me which one is a real word by saying "a" or "b". Let's try some for practice.

(Five practice words were given with appropriate feed back)

Now I will present some more words. I would like you to tell me whether "A" or "B" is a real word. I cannot help you with these just do the best you can. Ready, begin.

(The following word pairs will be presented on separate cards to the student)

a) baik	b) bape
a) lait	b) lote
a) blog	b) bloe
a) kake	b) dake
a) traif	b) trane
a) broun	b) broan
a) fite	b) fipe
a) filst	b) ferst
a) ait	b) afe
a) klass	b) cliss
a) dorty	b) derty
a) eap	b) eer
a) floap	b) flote
a) hawl	b) harl
a) joak	b) jope
a) neer	b) nerr
a) plaice	b) plice
a) seet	b) seaf
a) shart	b) shurt
a) teech	b) neach
a) threp	b) thrue
a) turt	b) tirn
a) fead	b) feem
a) felce	b) fense
a) thair	b) theer
a) fither	b) fether
a) bote	b) boaf
a) bair	b) beal
a) caim	b) pame
a) strate	b) strale

Test Five
Pseudoword Repetition

Instructions: On this tape recorder a voice is going to say a series of nonsense words. I want you to repeat each word right after the woman has said it. Remember these are not real words. Let's try one for practice. (Three practice words will be given. The words will not be repeated but corrections were given)

Now we are going to listen to some more nonsense words. The words are said just once. Just try your best to repeat the word right after the woman's voice says it.. (The following words were presented to students. A pronunciation guide to the pseudowords is provided)

Pseudowords	Corresponding Real Word
meskits	biscuits
tropaply	probably
ereshant	elephant
foltano	volcano
skapeddi	spaghetti
spapistics	statistics
teroscote	telescope
imbichent	indigent
kebestrian	pedestrian
karpigular	particular
etosprosee	apostrophe
adnesteric	atmospheric
panamity	calamity
carimature	caricuture
ponverlation	conversation
grishanthenum	chrysanthemum
troichipal	dirigible
zacradery	secretary
araminam	aluminum
phirotofical	philosophical
didliokrafy	bibliography
sarnatutical	pharmaceutical
onamifidy	anonymity
gysiolochipal	physiological
deconfiliation	reconciliation
iliodintratic	idiosyncratic
terspecacity	perspicacity
gonflidration	conflagration
nagmivishent	magnificent
gretiminary	preliminary

Test Six
Orthographic Choice

Instructions: I am going to show you a card with two words written on it. One of them is a real word. I would like to you to tell me which one is the real word by answering "a" or "b". Let's do some for practice.

(The student was presented with 5 practice trials with appropriate feedback. The following pairs of words were used):

room/rume, young/yung, turtle/tertle, snow/snoe, taik/take, goat/gote, please/pleese, sleap/sleep, streat/street, between/betwean, deep/deap, eazy/easy, face/fase, heavy/hevvy, hert/hurt, laik/lake, nead/need, roar/rore, sheep/sheap, smaok/smoke, tape/taip, toward/toard, wait/wate, clown/cloun, circus/sircus, wroat/wrote, wurd/word, cote/coat, few/fue, keep/keap.

Test Seven
Homophone Choice

Instructions: I am going to show you a card with two words written on it and then I am going to ask you a question. I would like you to answer "a" or "b" to my questions. Let's do some for practice.

(The student was given 5 trials with appropriate feedback)

Now I am going to show you some more pairs of words and ask you a question. I want you to answer "a" or "b". I cannot help you with these, just do the best you can.

(The following pairs of words were used with the accompanying question)

a) two	b) too	Which is a number?
a) be	b) bee	Which is an insect?
a) by	b) buy	Which do you do when you shop?
a) creak	b) creek	Which is water?
a) heel	b) heal	Which does a doctor do?
a) rose	b) rows	Which is a flower?
a) tail	b) tale	Which does a dog have?
a) ate	b) eight	Which is a number?
a) cents	b) sense	Which do you get in change when you buy something?
a) flew	b) flu	Which is something a bird did?
a) right	b) write	Which do you do with a pen?
a) groan	b) grown	Which do you do when you have a pain?
a) bare	b) bear	Which is an animal?
a) ant	b) aunt	Which is an insect
a) flower	b) flour	Which do you use in bread?
a) one	b) won	Which is a number?
a) plain	b) plane	Which flies in the sky?
a) pain	b) pane	Which one is made of glass?
a) sale	b) sail	Which one is on a boat?
a) hair	b) hare	Which one runs very fast?
a) blew	b) blue	Which one is a colour?
a) poor	b) pour	Which one needs money?
a) deer	b) dear	Which one is in a forest?
a) hall	b) haul	Which one is a large room?

a) stake	b) steak	Which one do you eat:
a) week	b) weak	Which one has seven days?
a) brake	b) break	Which one is found in a car?
a) pray	b) prey	Which one do you do in a church?
a) none	b) nun	Which one is a woman?
a) pair	b) pear	Which one is a fruit?

Test Eight
Semantic Choice

Instructions: I am going to show you two words and read them to you. I want you to tell me if they are in the same category. You are to answer "yes" if they are in the same category and "no" if they are not. Let's do some practice ones.

(The student was presented with 5 trials with appropriate feedback)

Now I am going to show you some more pairs of words and read them to you. Simply answer "yes" if they are in the same category or "no" if they are in different categories. I cannot help you with these, just do the very best you can.

(The following pairs of words were presented to the student)

hour day
soccer hockey
brother grandmother
gold copper
dog lion
red blue
fork knife
second year
golf football
bed table
cousin father
brass zinc
chair sofa
pig cat
pink brown
cherry lemon
apple banana
leg nose
ear finger
pan bowl

knife sister
tennis elephant
aunt pot
lead tiger
horse spoon
blue week
stove bear
desk grape
head hour
pear cow
minute swimming
rugby baseball
basketball nephew
uncle month
iron couch
mouse lamp
green dresser
stool purple
toe apple
peach mother

Test Nine
Vocabulary Test

Level C and Level D of Gates MacGinitie Vocabulary test were given.

Test Ten
Decoding

Instructions: I would like you to read some words. Some of the words may be difficult, just do the best you can. Ready. (The left hand column of words were presented to the students) Now I am going to give you another list of words which I would like you to read the same way. However, these words are different because they are not real words. They look a little like real words and you can read them by sounding them out, but they are not real words. Just sound them out like you think they should be said. (The right hand column of words were presented to the students)..

(The following words, written in lower case letters, courier 12 print will be presented to the student on an 8 x 11 sheet of paper)

Word Recognition Task

they	fik
money	lak
have	hok
friend	eld
said	pesk
machine	frim
should	thag
fruit	sposh
come	tung
ocean	mipe
does	shune
shoe	strale
put	darf
chef	noik
young	tain
sword	fleep
ancient	nebber
busy	ishing
print	baslet
obey	ansprit
was	juk
island	sen

could	isk
eye	rond
here	trab
sign	whit
once	bink
muscle	druk
high	kule
sugar	thade
want	sprone
cafe	furb
done	moig
aunt	beal
foreign	groat
neighbour	ritter
answer	tockens
laugh	macrens
climb	elegrund
ache	caf

Test Eleven
Sentence Span

Instructions: I am going to read some sentences to you. I want you to listen carefully. Your job is to remember the last word of each sentence in the order in which they are read.

First I will read you a set of sentences. Then I will ask you a question about one of the sentences. Then I will say "Remember" and you are to tell me the last word of each sentence in the correct order and then the answer to the question.

There will be eight sets of sentences and the number of sentences in each set will gradually increase during the task. If the task gets hard, try to remember as much as you can and don't be afraid to guess about the words or answers to the questions. Be sure to listen carefully in order to answer the questions as accurately as possible.

We will do some practice ones first. Do you have any questions? Here is the first practice set. Listen carefully to the sentences as I read them After each sentence I will pause so you know when I am starting a new sentence. (After each sentence pause 3 seconds).

The following sentences and questions were used:
Practice

Many animals live on a farm.
People have used masks since early times.

Question: What have been used since early times?

Remember:

You should have said farm, and times. Then you should have said masks, which is the correct answer to the question.

Try this second practice set. Listen while I read the sentences.

The baby's toy rolled under the bed.
They walked around to the back of the house.

Question: What rolled under the bed?

Remember

The words you should have said were bed and house. The answer to the question is the toy or the baby's toy.

Here is one more practice one.

The squirrel hid the acorns in the hollow tree.
It was so cold, the snow crunched under his feet.

Question: What crunched?

Remember

The answers are tree and feet and the answer to the question is snow. Do you have any questions?

Now I think you have the idea. Try to remember as much as you can and don't be afraid to guess about the words or the answers to the questions. Listen carefully.

Sarah wants you to give her a dollar
Mary tried to tell her teacher the right street.
Question: Who did Mary try to tell?

Both of the games were cancelled because of trouble.
Jennifer says she doesn't have the time.
Question: What was cancelled?

We waited in line for a ticket.
Sally thinks we should give the bird its freedom.
My mother said she would write an excuse.

Question: Where did we wait?

The cheerleader does not seem to have friends.
Beth can't go because she didn't get shoes.
Bob doesn't want to tell the teacher.
Question: Who can't go?

My little brother went in the wrong restaurant.
The teacher wanted to see me about my book.
You will be sorry if you break the window.
My friend wanted to learn about snakes.
Question: Who will be sorry?

If you work hard you can make a discovery.
We didn't buy the car because of the cost.
I would like to know your opinion.
It is important to think about safety.
Question: What didn't we buy?

The broken doll was not my fault.
Joe is having problems with his memory.
I have talked to my parents about the idea.
John is not is a very good mood.
They were all happy to be at the even.
Question: What was broken?

I can study if you give me a pencil.
Children like to read books about animals.
I will give Cindy the candy in a bowl.
The good news gave Ann a feeling of happiness.
Jeff likes to do homework in ink.
Question: What will I give to Cindy?

Test Twelve
Counting Span Test

Instructions: I am going to show you some pages with dots on them. I want you to count only the green dots. I want you to point to the green dot with your finger while you count out loud. Then I want you to remember the number of green dots on each page. Let's do one for practice.

(The student was presented with three practice cards with appropriate feedback and then the task was started).

Test Thirteen
Visual Spatial-Shading

Instructions: I am going to show you a grid with one square shaded. Then I am going to put a black page in front of you. Then I am going to place a blank grid in front of you and ask you a question After you answer the question I want you to put an X on the grid to show which squares were shaded. Let's do some for practice first. (Three practice trials were given with corrections)

Test Fourteen
Visual Spatial - Mr Cucumber Task

Instructions: I am going to show you a clown figure with some dots on it. Then I am going to put down a piece of graph paper. Then I am going to put down a blank clown figure. I am going to ask you a question about the clown and then I want you to draw circles on the blank clown face to show where the coloured dots were. Gradually there will be more dots on the figure. Three practice trials were given with corrections.

Test Fifteen
Concurrent memory Task

Instructions: (For shapes) I am going to say some numbers. As I say the number I would like you to take one card and put it on the correct pile according to its shape. For each number take one card. When I have finished saying the numbers you will have finished putting the cards into the correct piles Then I would like you to tell me the numbers I said and if possible tell me them in the same order that I said them to you. Let's do one for practice.

(For categories). I am going to say some numbers. As I say the number I would like you to take one card and put it on the correct pile according to its category. For each number take one card. When I have finished saying the numbers you will have finished putting the cards into the correct piles Then I would like you to tell me the numbers I said and it possible tell me them in the same order that I said them to you. Let's do one for practice.

(For blanks) I am going to say some numbers. As I say the number I would like you to take one card and put it on a pile. Because they are blank it doesn't matter which pile you put them on.. For each number take one card. When I have finished saying the numbers and you will have finished putting the cards into the correct piles Then I would like you to tell me the numbers I said and if possible tell them to me in the same order that I said them to you. Let's do one for practice.

Test Sixteen
Metacognitive Questionnaire

1. Reading the same story twice
   a) is boring so you shouldn't do it
   b) takes too much time
   c) helps you so you can tell it to someone else
   d) can help you understand the difficult parts
2. When you finish reading you should
   a) think about the story and make sure you understand it
   b) close the book and do something else
   c) not go back and read it over
   d) write a book report
3. Before you read a story why would you ask if you had to remember the story word for word or just the general meaning?
   a) I would study it differently
   b) it would help me to remember the story
   c) I would know what kind of answer the teacher wants
   c) I would take notes
4. A good reader
   a) is also good in all other school subjects
   b) may not be good in other subjects such as math
   c) has lots of books at home
   d) enjoys reading to himself/herself
5. What is the best reason for judging your reading when you finish?
   a) so you can tell your teacher that you're through
   b) so you can be sure that you understand the meaning
   c) so you can tell if the author was telling the truth
   d) so you know if you liked the story
6. If you cannot read a word in a story, you should
   a) guess it or make one up
   b) skip it
   c) use the rest of the sentence as a clue
   d) look it up in the dictionary
7. When you read
   a) it helps to know something about the story first
   b) short stories are easier to remember than long ones
   c) read only stories you like
   d) choose books with pictures
8. When you read you should not
   a) skip sentences that are hard to understand
   b) check to see if sentences make sense and fit together
   c) ask for help for new vocabulary
   d) go back and read the story again

9. The best way to focus on the important points of a story that you read is to
    a) read the story 3 or 4 times
    b) ask someone else to explain it
    c) take notes
    d) underline the main ideas
10. Being a reading detective means that you
    a) use a magnifying glass when you read
    b) read fast or slow depending upon the kind of story and reason for reading it
    c) like to read mystery stories better than animal stories
    d) can answer all the questions
11. The main goal or reading is
    a) to say all the words
    b) to read quickly without mistakes
    c) to find an answer
    d) to understand the meaning
13. Which is quicker?
    a) reading out loud
    b) reading silently to yourself
    c) taking turns reading in a group
    d) having someone read to you
14. What does the last sentence do?
    a) it ends the paragraph or story
    b) it ends with a period
    c) it tells us what the paragraph or story was about
    d) it repeats the first sentence
14. Skimming is
    a) reading all the short words and not the long ones
    b) a quick way of finding out what the story is about
    c) something that only poor readers do
    d) moving your fingers fast under the words
15. A really good plan for your reading is
    a) to skip the hard parts
    b) to read every word over and over
    c) to look back in the story to check what happened
    d) to read the end of the story first
16. Someone who is a really good reader
    a) practices reading a lot
    b) can say all the words correctly
    c) knows about lots of different things
    d) reads fast

17. Saying a story in your own words is important because
    - a) you don't have to worry about what the story means
    - b) then you know if you have summarized all the main ideas
    - c) you can tell if it is real or make-believe
    - d) you can tell the story in the order it happened
18. Inferring the hidden meaning when you read means that
    - a) you try to memorize what the author said
    - b) you need to use a dictionary to understand it completely
    - c) you state the fact
    - d) you figure out what happened even though the words didn't say it exactly

19 What does the first sentence usually do for a paragraph or story?
    - a) it begins the paragraph or story
    - b) it starts with a capital letter
    - c) it tells us what the paragraph will be about
    - d) it is indented

20. A good reading detective
    - a) gathers clues about the purpose, content and difficulty of the reading
    - b) reads the story first and asks questions later
    - c) reads very quickly
    - d) can sound out hard words

Test Seventeen
Concurrent Memory Task (coloured paper)

The instructions to this test are similar to the Concurrent Memory Task using digit except that this time rather than recalling digit sequences the student is asked to recall the coloured paper that were presented by pointing to a grid to indicate which coloured squares were presented and in which order.

Test Eighteen
Cloze Test

I am going to show you a story and read it out loud to you while you follow along. There are blank spaces in the story and I would like you to give me a word that you think could go into the blank space. I will read it all the way through and then go back and reread and stop at each blank. I will read any part of the story as often as you like. (Every fifth word was left out except for the first and last sentences).

Smart Birds (for grade three)

Everyone knows that birds like to eat seeds and grain. Birds also like to eat little stones called gravel. Birds have to eat the gravel because they don't have teeth to grind their food. The gravel stays in the bird's gizzard which is something like a stomach. When the bird eats seed, the gravel and the seed grind together. All of the seed is ground up. Tame birds must be given gravel. Wild birds find their own gravel on the road sides. Now you can see how smart birds are.

A Beaver's Home (for grade six)

A beaver's home, called a lodge, always has a flooded lower room. These homes are built on large ponds or streams. Mud and sticks are the main building materials. One room is built above the water and another room is built under water. The only way a beaver can get into the house is to dive and enter through an opening in the flooded room. The room serves two purposes: a storage area and a sanctuary from enemies. Occasionally the lower room becomes dry because the beaver's dam has been destroyed. This energetic animal has to quickly repair the dam or begin building a new home in another place.

Test Nineteen
Inconsistencies

Instructions: I am going to read you some short stories. I want you to follow along while I read. In the stories there is something wrong, something that does not make sense. When I have finished reading the story to you, you are to underline what you think is wrong with the story. Lets one for practice.

Mercury is the smallest planet closest to the sun. The heat from the sun is very strong there. Mercury goes around the sun quickly, in 88 days. The sun's heat is strong, so most **brugens** would melt. Mercury is smaller than the earth. It's the smallest planet in our solar system.

The first steam train was built in England almost two hundred years ago. In 1830, a famous race was held between a steam train and a horse. The train was called Tom Thumb. The idea behind the race was to **thrus** that steam trains were better than horses. But the train lost the race! As time went on, however, trains or locomotives became more important than horses.

Even with food all around, turkeys will not eat. Turkeys can really be called "silly birds" . Many die from lack of food. Straw is kept in their houses but some never seem to discover what it is used for. The **intelligent** young birds don't know enough to come out of the cold either. We will never understand the senseless turkeys.

Baby birds sleep, eat and grow up in nests. In bird families, the baby that opens his mouth the biggest and makes the most noise gets the most food. He may not be the largest bird, but he is the **quietest.** Birds drink by taking little sips of water. They hold their heads high. This lets the water run down their throats.

Hang gliding got its start in the early 1970's. California is likely to have the most hang glider pilots. Hang gliders are made by attaching a triangular said to a frame. The glider is about 18 feet wide. The pilot takes off by holding the glider and running **up** the windward side of a cliff. When airborne the pilot steers the glider with a control bar.

There are over three hundred thousand different kinds of plants. Some plants grow bigger and live longer than animals. Plants grow in many sizes and shapes almost everywhere in the world. Some are smaller than the period at the end of this sentence. These plants can only be seen with a **telescope.** Other plants, like the giant pine, tower high in the sky.

The Eskimos who live in the North often call themselves "People of the Deer" because an important source of food has been the reindeer. For a while, the herds of reindeer went down to dangerously low levels because of the arrival of fur traders. The Eskimos began trapping for extra furs to exchange for knives and guns, instead of just for their own food and clothing. They had to travel farther to set trap lines, and they needed more sled dogs to **trext** the furs, so they had to kill more reindeer to feed the dogs. As a result, the reindeer herds were much reduced. Eventually, the government saw what was happening and made a plan to build up their numbers. Now the herds are again increasing in size.

No one knows exactly how or where ice hockey started. However, field hockey was played in England more than one hundred fifty years ago, and some pucks and sticks have been found that show that ice hockey was played in Canada by British soldiers during the 1850's By 1890, a hockey association had been formed in Canada to administer and develop the game. Shortly after, hockey was **blasmor** into the United States at two universities and the game was soon very popular. At first, the game was played only for fun, but people were willing to pay to watch exciting games. So professional teams were set up and the National Hockey Association was formed.

Cycling is the name given to the use of bicycles for organized sport. It started as a sport more than one hundred years ago when two brothers in France held the first bicycle race. The early bicycles had a large front wheel and a smaller rear wheel, and they used hard rubber on metal wheels for tires. These **cars** were both dangerous and uncomfortable. Later on, the wheels were made equal in size, and the inflatable tire was invented so the ride was safer and more comfortable. By 1890 cycling was so popular that clubs were formed and competitions set up in most countries of the world. Today there is still interest in cycling clubs in North America, but bicycles are probably used mostly for enjoyment and healthy exercise.

Golf started in Holland as a game played on ice. The game in its present form appeared in Scotland. it became very popular there, and kings enjoyed it so much that it was called the royal game. James IV, however, thought that **cats** neglected their work to indulge in the fascinating sport, and so it was forbidden in 1457. At last someone persuaded James to try the game, and he relented when he found how attractive the game was. Golf immediately regained its former popularity, spreading gradually to other countries, and being introduced into North America in 1890. It soon gained a wide following and has grown in favour until there is hardly a town that does not boast of either a public or a private golf course.

Gold is a metal that has been considered valuable throughout history, because it is attractive, durable, quite malleable, and rare enough to make it expensive. During the last century, it was the gold discovered in the beds of running streams that sent people on the Gold Rush, to west California and north to the Yukon Territory. Gold miners at that time "panned" for the metal, putting gold-bearing earth and water together in a shallow pan. They swirled the water together in a shallow pan. They swirled the water around until the **heavy** sand was washed away, leaving the heavy grains of gold behind. Nowadays, newer mining methods are employed. However, using water to separate gold from the earth is still the most common method of mining gold. The various methods of obtaining gold with the use of water are called "placer" mining.

Baseball has often been called the national sport of the United States. It developed from games known in England as "rounders" and "town ball" and was played in U.S. colleges as early as 1825. Baseball's popularity has constantly increased because the rules are easily understood and the players require only **complicated** equipment. War, as it happens, has been responsible for the growth of the pastime. Many men learned it first in camps during the American Civil War and started teams after they returned home. Both World Wars extended it further, for wherever U.S. soldiers were stationed in foreign countries, they created an interest in baseball that remained after they left, In Japan, for example, baseball may now be as popular as it is in the United States.

Test Twenty
Use of Schema

Instructions: I want you to follow along as I read you the following story. I am going to ask you three questions about the story at the end. I will reread any parts of the story you want me to as many times as you want me to.

(The following stories were read to the students and reread as they requested)

The bees had been making honey all day long. At night it was cool and calm. I had slept well until I heard a loud noise near my window. It sounded as if someone were trying to break into my cabin. As I moved from my cot, I could see something black standing near the window. In fright I knocked on the window. Very slowly and quietly the great shadow moved back and went away. The next day we found bear tracks. The bear had come for the honey that the bees were making in the attic of the cabin.

1. Why do you think the bear walked away?
2. How did the person probably feel the next day? Why?
3. Did the bear get the honey?

Sally really wanted a little dog. One day she went with her parents to the pet shop. They looked at the fish, turtles, parrots, cats, and of course, dogs. Sally and her parents saw one nice puppy that acted very lively. It looked like a small bouncing black ball of fur. The puppy was a fluffy black poodle. It jumped around in its cage. When Sally petted the puppy, it sat up and begged. Sally and her parents laughed because the poodle looked so cute. They decided to buy the poodle. After all, who could resist such a cute dog?

1. Why do you think Sally wanted a dog?
2. Why do you think Sally and her parents chose the poodle?
3. How did the puppy make Sally feel? How do you know?

Last week a boy and girl from our school had a real adventure. They were going past the bank on their way home for lunch when two men ran out with a bag of money. The men had a car waiting for them and drove away very fast. When the police came the children told them what colour the car was and how big it was. They could even tell the police that one man was short and the other one was tall. Because the children were in the right place that day, the men were soon caught and the money was returned.

1. Did the children have good memories? How do you know?
2. What were the two men? How do you know?
3. At approximately what time did the robbery take place?

All the ranchers in the valley knew about the wild stallion named Blaze, a powerful horse with a red mane. Many of the local men tried to catch this rebel but failed each time. A reward was offered for his capture - dead or alive, because he encouraged other horses to run away with him.

Pete posted the men all along the secluded trails that Blaze usually followed. Each rider would pick up Blaze along the trail and force him into a narrow canyon, where Pete would be waiting.

The men succeeded in forcing Blaze into the narrow canyon. Pete was ready with his rope but Blaze came at him in a wild rage. Pete lost his balance but was able to roll over out of the way. Blaze saw his chance to escape and got away once again.

1. Describe how Pete's men worked as a team to help capture Blaze.
2. Were there many people around? How do you know?
3. How was Pete going to catch Blaze?

Many wild creatures that travel with their own kind know by instinct how to protect the group. One of them acts as a sentinel.

Hidden by the branches of a low-hanging tree, I once watched two white-tailed deer feeding in a meadow. At first, my interest was held by their beauty. But soon I noticed something which was quite unusual. They were taking turns at feeding.

One deer was calmly cropping grass, unafraid and at ease. The other, the sentinel, stood guard against enemies. The guard deer watched every movement and used its sensitive nostrils to "feel" the air. Not for a moment, during the half hour I spied upon them, did they stop their teamwork.

1. Why was the deer who was eating at ease and not afraid?
2. Why did the man stay hidden?
3. Why did the deer use its sensitive nostrils?

It was 1979 when the big tennis event happened. Tracy Austin, age 16, won the U.S. Tennis Open. When Tracy beat Chris Everett-Lloyd, she became the youngest player to win the Open. No player, male or female, ever won the Open at this young age.

Few people actually thought Tracy had a chance to win. Even her coach did not believe she could win. In fact, he vowed to quit smoking if she won. Tracy reminded him about the no smoking vow when the match was over.

Tracy Austin beat Everett-Lloyd by being steady and consistent. Everett-Lloyd was rocked by critical mistakes throughout the match. When the match was over, Tracy shouted, "I can't believe it! I really did win!"

1. Did Tracy's coach quit smoking?
2. Why did her coach say he would quit smoking?
3. Why did people think Everett-Lloyd would win?

Test Twenty-one
KTEA -Short Form

The KTEA was administered in the standardized manner outlined in the manual.

Test Twenty-Two
Coloured Progressive Matrices

Coloured Progressive Matrices was administered in the standardized format.